Bureau International des Poids et Mesures

Director's Report on the Activity and Management of the International Bureau of Weights and Measures

(1 July 2003 – 30 June 2004)

Note on the use of the English text

To make its work more widely accessible the International Committee for Weights and Measures publishes an English version of these reports.

Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

TABLE OF CONTENTS

MEMBER STATES OF THE METRE CONVENTION AND ASSOCIATES OF THE GENERAL CONFERENCE

as of 1 July 2004

Member States of the Metre Convention

Argentina
Australia
Austria
Belgium
Brazil
Bulgaria
Cameroon
Canada
Chile
China
Czech Republic
Denmark
Dominican Republic
Egypt
Finland
France
Germany
Greece
Hungary
India
Indonesia
Iran (Islamic Rep. of)
Ireland
Israel
Italy
Japan
Korea (Dem. People's Rep. of)
Korea (Rep. of)
Malaysia
Mexico
Netherlands
New Zealand
Norway
Pakistan
Poland
Portugal
Romania
Russian Federation
Serbia and Montenegro
Singapore
Slovakia
South Africa
Spain
Sweden
Switzerland
Thailand
Turkey
United Kingdom
United States
Uruguay
Venezuela

Associates of the General Conference

Belarus
Chinese Taipei
Costa Rica
Cuba
Ecuador
Hong Kong, China
Jamaica
Kenya
Latvia
Lithuania
Malta
Panama
Philippines
Slovenia
Ukraine
Viet Nam

THE BIPM AND THE METRE CONVENTION

The International Bureau of Weights and Measures (BIPM) was set up by the Metre Convention signed in Paris on 20 May 1875 by seventeen States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

The BIPM has its headquarters near Paris, in the grounds (43 520 m^2) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

The task of the BIPM is to ensure worldwide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the coordination of corresponding measurement techniques;
- carry out and coordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the International Committee for Weights and Measures (CIPM) which itself comes under the authority of the General Conference on Weights and Measures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on

the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to measurements of length and mass, and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry and radiometry (1937), ionizing radiation (1960), time scales (1988) and to chemistry (2000). To this end the original laboratories, built in 1876 -1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories, in 1984 for the laser work and in 1988 for a library and offices. In 2001 a new building for the workshop, offices and meeting rooms was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, the *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The president of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

1. The Consultative Committee for Electricity and Magnetism (CCEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;
2. The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. The Consultative Committee for Thermometry (CCT), set up in 1937;
4. The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
5. The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
6. The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ-rays, electrons), Section II (Measure-ment of radionuclides), Section III (Neutron measurements), Section IV (α-energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);
7. The Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954);
8. The Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
9. The Consultative Committee for Amount of Substance: Metrology in chemistry (CCQM), set up in 1993;
10. The Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up un 1999.

The proceedings of the General Conference and the CIPM are published by the BIPM in the following series:

- *Report of the meeting of the General Conference on Weights and Measures*;
- *Report of the meeting of the International Committee for Weights and Measures*.

The CIPM decided in 2003 that the reports of meetings of the Consultative Committees should no longer be printed, but would be placed on the BIPM website, in their original language.

The BIPM also publishes monographs on special metrological subjects and, under the title *The International System of Units (SI)*, a brochure, periodically updated, in which are collected all the decisions and recommendations concerning units.

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) and the *Recueil de Travaux du Bureau International des Poids et Mesures* (11 volumes published between 1966 and 1988) ceased by a decision of the CIPM.

The scientific work of the BIPM is published in the open scientific literature and an annual list of publications appears in the *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

STAFF OF THE
INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES
on 1 July 2004

Director: Prof. A.J. Wallard

Length: Prof. A.J. Wallard
Mr R. Felder, Mr J. Labot, Dr L.-S. Ma[1], Dr L. Robertsson,
Dr L.F. Vitushkin, Dr M. Zucco[2]

Mass: Dr R.S. Davis
Mrs P. Barat, Mrs J. Coarasa, Dr H. Fang, Mrs C. Goyon-Taillade,
Mr A Picard

Time: Dr E.F. Arias
Dr Z. Jiang, Mrs H. Konaté, Dr W. Lewandowski, Dr G. Petit,
Mr L. Tisserand, Dr P. Wolf[6]

Electricity: Dr T.J. Witt
Dr M. Stock[3]
Mr R. Chayramy, Mr F. Delahaye, Mr R. Goebel, Mr A. Jaouen,
Dr D. Reymann, Mr S. Solve

Ionizing radiation: Dr P.J. Allisy-Roberts
Dr D.T. Burns, Mr S. Courte, Mrs C. Kessler, Dr C. Michotte,
Mr M. Nonis, Dr S. Picard, Dr G. Ratel, Mr P. Roger

Chemistry: Dr R. Wielgosz
Dr M. Esler, Mr P. Moussay, Dr J. Viallon

Publications and Information technology: Dr J. Williams
Mr L. Le Mée, Dr J.R. Miles, Mr G. Petitgand

BIPM key comparison database: Dr C. Thomas[4]
Dr S. Maniguet

Quality systems, ISO and ILAC liaison: Dr R. Köhler

Secretariat: Mrs F. Joly
Mrs D. Le Coz[4], Mrs G. Négadi, Mrs J. Varenne

Finance, administration and general services: Mrs B. Perent
Mr F. Ausset, Mrs D. Etter, Mrs M.-J. Martin, Mrs D. Saillard[4]

Caretakers: Mr and Mrs Dominguez[5], Mr and Mrs Neves[5]
Housekeepers: Mrs A. Da Ponte, Mrs M.-J. Fernandes, Mrs R. Prieto
Gardeners: Mr C. Dias-Nunes, Mr A. Zongo[5]

Workshop and site maintenance: Mr J. Sanjaime
Workshop: Mr F. Boyer, Mr M. de Carvalho, Mr J.-B. Caucheteux, Mr D. Rotrou
Site maintenance: Mr P. Benoit, Mr P. Lemartrier

Emeritus directors: Prof. P. Giacomo, Dr T.J. Quinn

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1 Senior Research Fellow.
2 Research Fellow.
3 Head of special projects.
4 Also Publications.
5 Also site maintenance.
6 On secondment at BNM-SYRTE, Observatoire de Paris.

Director's Report
on the Activity and Management
of the International Bureau
# of Weights and Measures

(1 July 2003 – 30 June 2004)

1 INTRODUCTION

1.1 General introduction and summary of scientific work

I have pleasure in introducing the Director's Report for 2003-2004. During this period we have seen three notable events: the 22nd General Conference on Weights and Measures (CGPM); the end of the transition period for the CIPM MRA and the retirement of Dr Terry Quinn as Director of BIPM.

The last General Conference was a critical one for BIPM as, for the first time since the 1960s, the CIPM requested an increase of the dotation in real terms. The reasons for this, already predicted at the time of the 21st CGPM in 1999, were based on the huge increase in BIPM's workload that resulted from the implementation of the CIPM MRA, the increase in coordination activities with NMIs and with other intergovernmental or international organizations and the need to extend our work on metrology in chemistry and laboratory medicine. In addition, our core scientific and technical programme in existing areas was responding to ever-increasing demands from Member States. Up until recently, BIPM had been able to maintain its work in all these areas by re-evaluating its priorities and making some modest reductions in programmes. By 2002 it had, however, become clear that such a situation would be unsustainable for the next four-year period. In facing up to this, the CIPM accepted the then Director's proposal that the Photometry and Radiometry section be closed and the work in the Length section refocused onto frequency comb-related activity but with the retention of its existing small programmes on nanometrology and gravimetry. These decisions helped provide evidence to Member States that the CIPM and the BIPM were reacting to the external situation and were themselves prepared to adjust BIPM's work to meet changing priorities. The General Conference agreed the proposed work programme for 2005-2008 but voted, in its Resolution 12, a dotation and an additional discretionary contribution smaller than the CIPM considered necessary. Consequently, further financial savings are required for the BIPM to deliver the proposed 2005-2008 work programme. This Resolution also included a request to Member States to support a programme of Research Fellowships at the BIPM as well as secondments of NMI staff to the BIPM. Suggestions for projects were sent to directors of NMIs at the end of last year and I look forward to responses.

The Programme and Budget proposals to the 22nd General Conference had been prepared after extensive consultation with directors of NMIs, based on

two wide-ranging questionnaires in 2001, and followed by discussions at subsequent meetings of directors. The General Conference accepted, unanimously, the 2005-2008 work programme as proposed. This included a further extension to BIPM's scientific and technical activities in chemistry and a watt balance experiment. The General Conference also emphasized the importance of the proposed increased activity in international coordination. This trend is already evident and during the last year we have been increasingly active in our general relations with ILAC, ISO and OIML. We have also continued our collaboration with organizations which are expert in, or representative of, the new application areas for metrology. Among the latter are the WHO, the WMO, and the Codex Alimentarius as well as specialist bodies such as the IFCC. These partnerships are essential for success in applying our concepts of metrological traceability and uncertainty in areas where others know more about the science behind them. These partnerships have been enthusiastically welcomed by the organizations concerned and I am confident we shall see considerable progress in the years to come.

December 2003 saw the end of the formal transition period for the CIPM MRA. The Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) met twice during this report period and, amongst other matters, finalized its position on the steps necessary to demonstrate international confidence in the review processes for Quality Systems. The BIPM key comparison database (KCDB) is now well populated with CMC and comparison report data and almost all current areas of metrology are represented. We shall continue to modify and improve the database as well as the way in which data is presented. We now believe the KCDB is reaching a stage of maturity at which we can begin actively to promote and market it to users outside the NMI community. The General Conference and recent directors' meetings supported this policy. In collaboration with a number of NMIs, there have, therefore, been discussions with several regulatory and legislative bodies who we hope will develop enough confidence in the CIPM MRA processes so as to use and refer to it in their own procedures. We have also set up a joint working party with ILAC so as to develop closer links and promote mutual dependence between the CIPM MRA and the ILAC Arrangement. As informing users of our progress and spreading awareness of the KCDB is an important part of our communication strategy we continue to develop the BIPM website and have launched a "KCDB Newsletter" to over 1000 recipients in June 2004.

At the time of writing, there are 16 Associates of the CGPM. We warmly welcome them and note with interest that the relevance of the CIPM MRA to trade was a key element in their decision to join. Currently we are discussing Associate status with several other States or Economies, including a joint economic group membership.

BIPM's scientific and technical programme, voted by successive General Conferences, is carried out under Article 6 of the Metre Convention (1875) and under Article 7 of the 1921 Rules annexed to the Metre Convention, and has a number of objectives. These are laid down in detail by the CIPM in its document "The role of the BIPM", the latest version of which was presented to the 22nd CGPM in the Report "*Evolving Needs for Metrology in Trade, Industry and Society and the Role of the BIPM*". Firstly, it gives us the responsibility to conserve and disseminate the primary standard of mass – the international prototype of the kilogram; to establish and disseminate International Atomic Time (TAI) and Coordinated Universal Time (UTC); and to provide unique facilities such as the SIR and those comparison or calibration facilities agreed by the CIPM and the General Conference. In addition, and importantly, it gives BIPM staff the technical credibility they enjoy with NMIs and with international organizations. As a result, we can run Consultative Committees effectively and can pilot a number of key comparisons. In addition, our scientific and technical expertise and broad knowledge of what is happening world-wide enables us to provide a high level of technology transfer from the BIPM during meetings, calibrations and comparisons. The content of our scientific and technical work has, however, to be chosen carefully to meet NMI needs and to avoid unnecessary duplication. Questionnaires, Consultative Committee discussions and regular NMI contacts ensure that we have the essential high quality information that enables us to propose and formulate our work-programmes and to ensure that the results can be taken up and exploited as widely as possible. The high level of appreciation of our scientific and technical role was clearly shown in the replies by NMI staff to the two questionnaires in 2001 mentioned earlier. Two notable steps in the last year have been the agreement reached on the nature of the new organic chemistry programme in pure material analysis and the recent review of NMI requirements for 1 V and 10 V comparisons of Josephson reference standards.

During the report period, the BIPM has organized some twenty meetings of Consultative Committees, working groups, Joint Committees, or liaisons with other bodies. In addition, the CIPM met at the time of the General Conference, and the JCRB met at BIPM and at CENAM (Mexico).

Committee work, therefore, continues to consume a large part of our scientific and support resources. In order to enable the BIPM to cope with producing reports of the greatly increased number of Consultative Committee meetings, the CIPM decided to publish them as web-based reports in their original language. As work associated with the CIPM MRA becomes less time consuming, many Committees are returning to technical matters, amongst which is the enormous progress made by femtosecond frequency combs and optical frequency standards. This was reviewed recently at two meetings of the CCL/CCTF joint working group. This Joint Committee will now regularly review a number of radiations as possible secondary representations of the SI second, and has already recommended a value and uncertainty for the microwave-based rubidium transition at around 6.8 GHz. We expect more reviews of a number of optical transitions in the near future. As a result of the work of the Length section and its NMI collaborators, we believe that comb techniques will not contribute significant uncertainties to measurements of these frequencies against the caesium standards. If, as many believe, optical 'clocks' surpass the performance of caesium clocks, a path is opened up towards an eventual redefinition of the second.

Some eighty students from thirty countries attended a highly successful BIPM Metrology Summer School in July and August 2003. The School had two main aims: firstly to provide a broad review of metrology through lectures given by world leading speakers including several Nobel Prize winners. Secondly, we wished to create an opportunity for younger people from NMIs to meet and make the contacts and friendships essential for the future of the metrology community. The proceedings have been published on CD and as a result of students' feedback we intend to hold a second Summer School at a date to be decided.

Our work with IFCC and ILAC in the Joint Committee for Traceability in Laboratory Medicine (JCTLM) continues to make excellent progress. The first lists of reviewed reference materials have been published on the JCTLM database and more are to follow. The next priorities for this Committee's work include ways of dealing with biological reference materials and their traceability as well as the promotion of this work to regulators. We have also made considerable progress with the European Commission in relation to its recognition of the JCTLM database as providing the lists of 'standards of a higher order' which are required to implement the technical aspects of the European Union's Directive on *In Vitro* Diagnostic Devices.

At BIPM itself, we have made a number of organizational changes to reflect our increased activity with ILAC and ISO, and the new responsibilities of the Electricity section. The Information Technology group is now within the Publications section, reflecting the close links between IT and the BIPM's web work.

Our Quality System now is fully operational for the BIPM's measurement services. All sections have been subject to on-site peer reviews by NMI experts. The System is now being extended to other external services, such as the JCRB and '*Circular T*'.

We continue to work to promote the Metre Convention, the BIPM and the CIPM MRA to external audiences. The Director and senior staff represent the BIPM at RMO events and speak regularly at conferences and specialist meetings. Within the limits of time and availability, we shall try hard to maintain this commitment. These engagements are listed in the travel commitments reported here. In addition, we have hosted a number of general visits to raise the BIPM profile in the academic, industrial and other appropriate communities. We are also committed to enhancing our website as the main information resource for the Metre Convention, to update it regularly and to use it to publicize specific metrology related events.

BIPM continues to be an exciting and lively place in which to work. In my experience, we combine a unique blend of scientific, political, economic and social functions. Optimizing the demands or needs of these constituencies is not a particularly easy task, but I am grateful to the BIPM staff for the positive and enthusiastic way in which they respond to change and to external priorities.

Finally, I end my first Director's Report with a tribute to my predecessor. Terry Quinn has rightly been applauded and widely recognized for his personal contribution to world metrology for many years. That BIPM is in a sound scientific, technical, and financial position is testimony to his leadership over the years. We shall miss his day to day presence but are delighted to see him finalizing his '*G'* experiment as well as in his role of Emeritus Director and personal member of Committees. We wish him and his wife a long and happy retirement.

The detailed scientific and technical reports provided by section heads are given below. I would, however, like to draw your attention to one or two of the more significant achievements and activities from each section during the last year.

Length: The Length section has successfully carried out two 'campaigns' of femtosecond comb-based laser calibrations as a result of which we have found ways of improving the realization of the metre using traditional 633 nm lasers. The value attached by the international community to our comparison and calibration activity was evident from the enthusiastic support of the CCL for a new key comparison in the area. This has now been launched as BIPM.L-K11 and will incorporate a wider range of laser sources than before. It will also encompass comparisons carried out by the RMOs.

The major achievement during the year was undoubtedly the work, published in *Science*, on the limitations of combs in frequency comparisons and in relating optical and microwave frequencies. The paper reported that agreement between comb measurements can reach the 10^{-19} level so opening up the possibility of direct comparisons between optical and microwave clocks with measurement uncertainties which should not be dominated by the measurement process. The paper attracted considerable attention from the technical press. Our efforts to measure the 3.39 μm methane stabilized laser has been hampered by reference laser problems but the necessary improvements now are nearing completion and we hope to be able to report a comb-based value for the frequency within the next year.

Our development of compact lasers for use in the BIPM watt balance, calculable capacitor and gravimeter is showing very satisfactory performance and we are discussing their possible exploitation with a commercial company.

The meeting of the CCL in September 2003 was preceded by a meeting of the Working Group on the *Mise en Pratique* which made a partial revision of the recommended radiations list (Recommendations CCL 2a, b, c) and by a meeting of a Joint Working Group CCL/CCTF. This Joint Working Group set the criteria for radiations to be considered as secondary representations of the second and, at a later meeting, recommended a value for the microwave rubidium transition as a possible secondary representation of the second. It expects to consider more candidates, probably from the optical region, at its next meeting.

Mass: Six new prototype kilograms (Nos. 86 to 91) have been manufactured and their mass stability has been studied over several months. This work at last removes the backlog of longstanding orders for new prototypes. We continue to support the world-wide effort to redetermine the Avogadro constant. In addition, staff resources from the Mass section have been redirected to the BIPM watt balance project. We have carried out calibrations

of four national prototype kilograms and have introduced a new calibration service for the volume magnetic susceptibility of artefacts used with the BIPM susceptometer. In the midst of these activities, we have introduced a Quality System for all calibration services and have undergone a successful peer review.

Time: The automated calculation procedure applied for International Atomic Time (TAI) has shortened the delay in the publication of *Circular T* and has rendered the complete process more reliable. Starting in March 2004, the Type A and Type B uncertainties of TAI time links are published in *Circular T*. The medium-term stability of TAI, expressed in terms of an Allan deviation, is estimated to be about 0.6×10^{-15} for averaging times of 20 d to 40 d. The accuracy of TAI is based on the data from nine primary frequency standards that include, at present, five caesium fountains (IEN CSF1, BNM-SYRTE FOM, BNM-SYRTE FO2, NIST-F1, and PTB CSF1). The scale unit of TAI has been estimated to match the SI second to within 2×10^{-15} since July 2003. An important part of the activity of the section deals with studies of time and frequency comparison using navigation satellite systems. The network of international time links, which classically relied only on the Global Positioning System (GPS) common-view technique based on C/A-code measurements obtained from one-channel receivers, has been enriched with the addition of new techniques of clock comparison. As a conclusion of the pilot experiment to test the use in TAI links of dual-frequency P-code measurements from geodetic type GPS receivers, four of these links have been incorporated to TAI. The number of GPS multi-channel receivers has increased in the past year, and the TWSTFT observations in Europe and North-America are now performed on a daily and sometimes sub-daily frequency. Calibration programmes of GPS receivers have been organized and run by the section, with almost 50 % of the receivers participating to TAI calibrated.

Research work is also dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. The BIPM Time section and the USNO (United States) jointly provide the Conventions Product Centre of the International Earth Rotation Service with the responsibility of establishing conventions for space-time reference systems; the "*IERS Conventions* (2003)" have been published. Other research subjects are pulsars, future clocks in space and atom interferometry.

As a part of the activities of the Conventions Product Centre of the International Earth Rotation Service, a position of visiting scientist for one

year has been provided at the BIPM. Dr Jim Ray (US National Geodetic Survey) benefits of this position since 1 September 2003.

Electricity: This has been an eventful year for the Electricity section, especially with the arrival in the section of three colleagues from the Photometry and Radiometry section and the beginning of two major projects, the watt balance and the calculable capacitor, described in another section of this report. Another important event was the successful establishment of the Quality System that included external audits by some of the world's foremost experts in the fields of voltage, resistance and capacitance metrology. As an aid for setting priorities in the work of the section, we have circulated a questionnaire to NMIs concerning their intention to participate in possible future BIPM direct comparisons of Josephson standards. Of the 36 specialists polled, 34 responded to the questionnaire and 32 expressed a wish to participate in a BIPM comparison. These results show a remarkable level of interest in this BIPM activity. Highlights of the technical activities of the year include the successful testing of the programmable array given to us by the PTB. We compared voltages of two segments of this array with themselves as well as the voltage across all segments with an array of SIS junctions and found no significant differences to within a standard uncertainty of 0.1 nV. Also, in the area of voltage metrology we participated in a EUROMET comparison of Josephson standards at 1.09 V and obtained agreement within 0.07 nV with a standard uncertainty of 0.16 nV. This provides a solid link between the ongoing BIPM key comparisons of Josephson standards and the EUROMET comparison results. In the area of impedance metrology, we have made advances in realizing and testing series and parallel combinations of quantum Hall effect devices. We have also developed a method of extending the frequency range of our most accurate capacitance measurements to cover the interval from 500 Hz to 6000 Hz through the use of a quadrature bridge containing resistors of known frequency dependence and using divider ratios between 1/4 and 4/1. Our investigations of noise in dc measurements clearly demonstrate that polarity reversal does not affect $1/f$ noise. We have also verified the accuracy of our calculations of the spectral density and Allan variance from noise voltage measurements by showing that the spectral density agrees to within a few percent with the Nyquist expression for thermal noise in a room temperature resistor. Our collaboration with the NIST now includes the characterization of the noise in measurements of 25 Zener-based voltage standards with an array of Josephson junctions and a digital voltmeter. The results agree with a noise model containing two spectral terms, white and $1/f$ noise, and confirm

trends observed in some earlier BIPM work that indicate significant lower noise in certain Zeners. We have had some interesting results using a new scheme to deduce temperature coefficients of Zeners using very low-frequency temperature modulation.

The activities of the section now cover the work on thermometry which was transferred from Photometry and Radiometry. The measurements for the CCT key comparison of water triple point cells were finished in July 2003, with the exception of one additional cell which was provided later as a replacement for a cell with unsatisfactory behavior. In total, 20 laboratories participated in this comparison, underlining the great importance of the water triple point as defining the SI unit of temperature, the kelvin. The results of this new comparison (CCT-K7) are of a much better quality than those of the previous comparison as we have made substantial improvements to our instrumentation. The report is currently under preparation and will be distributed in mid-2004.

The co-operative project with the NMIJ/AIST on the thermodynamic temperature determination of metal carbon eutectic alloys was limited to one year as a consequence of the closure of the Radiometry and Photometry section. Metal carbon eutectics are candidates for high-temperature fixed points in a future temperature scale. In spite of the short time, the feasibility of all necessary steps of the project was demonstrated. A new technique for the characterization of optical defects of the imaging system was developed.

Ionizing Radiation: We have replaced the medium-energy x-ray tube after 30 years service and the reference beams are being re-established. New high-voltage dividers have been constructed and installed on both x-ray facilities. A Compton x-ray spectrometer is being set up to confirm simulated mammography spectra prior to the completion of two comparisons. Verification of the correction factors (experimental and calculated) for the 250 TBq ^{60}Co beam is progressing and a new water phantom has been constructed. The accurate measurement of specific heat capacity is underway for the core of the new graphite calorimeter standard for absorbed dose. Following the implementation of Monte Carlo calculated correction factors for the BIPM x-ray air kerma standards, the results for 23 comparisons are now published in the KCDB. Two new dosimetry comparisons have been made and 32 national secondary standards have been calibrated. We have successfully implemented the quality system for calibrations and an external expert has audited this.

In the radionuclide field, six key comparisons are underway with measurements just beginning for the ^{125}I comparison, reports being written for the ^{241}Am, ^{54}Mn and ^{65}Zn comparisons, and draft reports already circulating for the ^{192}Ir and ^{90}Y comparisons. The BIPM radionuclide measurement facilities, particularly the electronics, are being updated to cope with this increased workload. In addition to several CCRI(II) comparison ampoules, six laboratories have submitted eight different radionuclides to the International Reference System (SIR) this year. In the last twelve months, a further 31 SIR comparison reports have been published in the KCDB. In addition to the reports in progress for the remaining eight ongoing comparisons, a further two new radionuclide comparisons and ten updates are in progress. Collaboration continues with the NPL on the SIR efficiency curves to improve the mathematical model and reduce the uncertainties. Impurity activity levels were measured using the BIPM Ge(Li) gamma spectrometer for seven radionuclides submitted for various comparisons.

Chemistry: The last General Conference endorsed the priority we attach to chemistry and two additional staff have been recruited, although they will join us just after the end of the formal period covered by this report. Their main area of activity will be in organic chemistry as part of the pure material reviews endorsed by the CCQM.

Until recently, therefore, the main focus of the section's work has been on gases. This has proved to be remarkably successful and good progress has been made with a relatively small team. The BIPM is coordinating the ozone reference standard comparison (CCQM-P28). Fourteen laboratories have participated in the comparison since July 2003, and a further thirteen laboratories are expected to participate. An informal comparison of the newly acquired ozone reference standard of the IMGC with the BIPM-SRP27 reference standard has also been performed. A collaboration with the BAM has been initiated to develop the use of a generalized least-squares method to develop expressions for the degree of equivalence of ozone reference standards.

The construction of BIPM-SRP33, in collaboration with the NIST, was completed at the BIPM in July 2003. The instrument has been used to investigate possible sources of bias in SRP measurements. The accuracy of the temperature measurement in the SRP has been evaluated, and biases that were found have been removed by the development and installation of a temperature control unit to equilibrate gas cell temperatures within the instrument. We have also investigated the pressure difference in the gas cells

of SRPs and the effect of optical design on the optical path length. Modified optical window holders have been designed and constructed allowing confirmation of the effect of multiple reflections within the gas cells. A feasibility study on the incorporation of a laser based light source into the SRP has been completed.

A primary gas standard facility for the dynamic preparation of nitrogen dioxide gas standards is being developed. The new system has been tested, and analysis of the Allan variance of time series measurements has confirmed that it now meets the required stability specifications. The completed facility will ultimately act as a primary reference for NO_2 mass fraction measurements for gas-phase titration.

A gas-phase titration (GPT) facility as a second potentially primary method for ozone concentration measurements has been constructed. Four molblocs have been purchased and are being integrated into the system to allow real time measurement of gas flow at considerably reduced uncertainty. Validation of the facility is currently underway. It is planned that the redesigned facility will participate in CCQM-P28.

A facility for the comparison of NO gas standards with nominal amount fractions of 50 μmol/mol has been established. It has been demonstrated that NO gas standards can be analyzed with a measurement uncertainty which is of the same order of magnitude as the uncertainty in their value determined from their gravimetric preparation. The completed facility will be used to ensure that the measurements of the amount fraction of NO in the GPT system are traceable to primary gravimetric gas standards. The BIPM has recently proposed a CCQM pilot study for the comparison of NO gravimetric mixtures using the NO facility.

The KRISS together with the Chemistry and Mass sections have prepared two papers describing the measurement of argon mole fractions in air and their importance to mass metrology. These were submitted for publication in *Metrologia* in June 2004.

A detailed BIPM work programme in the field of organic pure substances was presented to the CCQM Working Group on Organic Analysis in September 2003 and the CCQM in April 2004.

The long-term aim of the programme is to enable the BIPM to engage in and support the CCQM international programme of purity assessment comparisons and contribute to the development of robust approaches and methodologies for the determination of purity. The BIPM has prioritized the

requirements in laboratory medicine for pure clinically relevant analytes, which would be required for the establishment of reference measurement systems. The initial period of the programme will focus on the comparison of purity assessments of clinically relevant steroids and therapeutic monitored drugs. The BIPM has established collaborative projects with the LGC and the NMIJ/AIST to coordinate these comparisons.

The Chemistry section provides the secretariat for the JCTLM. The first meeting of the JCTLM Executive Committee was held at the BIPM, and a JCTLM list of 'higher order reference materials and measurement procedures' has been published on the BIPM's website.

Special projects: Two new projects have been launched with the approval of the General Conference and the CIPM. These are essential to maintain the BIPM as a dynamic organization meeting the changing needs of world metrology. In deciding to start this work, we were able to make a long-term commitment to maintain a calculable capacitor and decided that the time was right for BIPM to embark on a watt balance needed to monitor the international kilogram prototype.

Calculable capacitor: This is a co-operative project with the NML-CSIRO and aims at the development of a new advanced version of the calculable capacitor. Two calculable capacitors based on advanced design techniques and improved technology will be constructed by October 2006, with the objective of an uncertainty of 1 part in 10^8. The BIPM workshop has fabricated a measurement jig which will serve to test the quality of the electrode rods of the capacitors fabricated by the NML-CSIRO. Their straightness is fundamental for successful operation of the instruments. BIPM will also contribute an improved interferometer for the measurement of the effective length of the electrodes. We will also develop software for the calculation of the interference patterns in a multi-beam interferometer and for simulation of the effects of misalignments of the optical components. We also plan to include one of BIPM's compact iodine-stabilized modulation-free Nd:YVO_4/KTP lasers in the optical system.

Watt balance: BIPM's approach to the watt balance differs from those in other NMIs as we propose to make simultaneous measurements of the moving and static parts of the classic watt balance, and also to operate with a cryogenic technique which will help reduce some of the errors found in other approaches. We have started to use finite-element analysis to study different forms of the magnetic circuit. A closed, symmetric system with the magnets and the air-gap inside the circuit presents several advantages: screening from

external magnetic fields, high uniformity of the flux density in the air gap and compact design. We are currently working with a commercial company on the fabrication of the system. Alignment is a critical factor in all watt balances and we are paying close attention to techniques to align the magnet with respect to the local gravitational acceleration and to align the coil with respect to the magnet. Two systems to generate the relative movement of the coil and the magnet were studied: in one case, the magnetic circuit is moved and in the other case the coil. As we plan to carry out the weighing mode and the moving mode simultaneously, we have to move the coil through the magnet while a current is flowing. This entailed an estimation of the effect of eddy currents. At cryogenic temperatures, the related forces are significant but should cancel over a whole cycle of measurement. We have verified that for certain varieties of SmCo magnets, the temperature coefficient is very small. This opens up an opportunity for the construction of the magnetic circuit with a much lower temperature coefficient than in existing experiments.

Publications and Information Technology: The arrangements with the IOPP to manage much of the production process for *Metrologia* continue to work well and we now also have a planned programme of special issues reaching out for the next three years. The main event of the year was, however, the launch of the new BIPM website. We have already had a very positive response to the new version and the links provided to the various databases managed by the BIPM. As with many other organizations, the website is our main interface with external users, and we have taken full advantage of the functionality to use it for all papers related to meetings and to the publication of the relevant reports.

In Information Technology, the main server was replaced last year and now offers better performance. In addition, we have introduced a more sophisticated firewall system and enhanced virus protection.

The BIPM key comparison database, **KCDB:** The work on the KCDB continues as before with the regular updating of Appendix B with reports of key and supplementary comparisons. Some 570 comparisons are now in the database and approximately one new comparison report arrives each week.

The CMC data in Appendix C continue to expand and we are continually checking input data against the JCRB rules and procedures. Modifications to the way in which electricity CMCs were specified have resulted in a simpler and more compact way of specifying uncertainties and the information behind the CMC statement. A particularly important task will be to make

sure that CMCs arrive with a statement that they comply with Quality Systems reviewed by the relevant RMO committee. This assumes greater importance now that the CIPM MRA transition period is at an end.

The KCDB is aimed at external users in NMIs, companies and regulators and so requires continual modification to reflect the needs of users. No major restructuring was needed in 2003-2004, however several small but significant modifications were needed to increase the functionality and utility of the site for users and those in the RMOs who are responsible for CMC submissions. The internal processes have also been formalized in procedures within the BIPM Quality System, and the KCDB recently passed the internal review.

We are now beginning to promote the KCDB to new users. At the moment, such activity is relatively low key, but several presentations have been made at relevant meetings, and we launched a KCDB Newsletter in June 2004.

Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB): From its first meeting in 2003, the JCRB has paid particular attention to actions related to the end of the CIPM MRA transition period. RMOs were asked to submit a report on their review and acceptance of Quality Systems in participating NMIs, by 5 April 2004. Discussions on these reports at the 12th meeting of the JCRB, held in Querétaro (Mexico), in May 2004, resulted on a deadline of 31 December 2004 for completion of all Quality System implementations. After this date, all published CMCs that are not supported by a Quality System reviewed and accepted by its RMO and the JCRB will be deleted from Appendix C. A workshop is being planned for 30 September 2004, where the BIPM will present its Quality System and RMOs will make presentations on their procedures to review the Quality Systems of their member NMIs.

With the CMC submissions in thermometry and time and frequency currently undergoing inter-regional reviews, all metrology areas are now participating in the MRA. It is foreseen that after the May 2005 meeting the JCRB activities will become more routine and it may be necessary to reassess the convenience of meeting twice a year.

Quality System: The first milestone for the introduction of a Quality System compatible with ISO/IEC 17025 has been achieved as planned at the end of 2003, and all measurement services which issue a calibration certificate, including supporting measurement services, have now been internally audited and peer reviewed. In 2004, the KCDB and the Time section were added to the system. The calculation of TAI and the distribution of a stable

reference frequency were both successfully audited internally and externally, whereas the KCDB has only been subject to an internal audit. The second round for the yearly internal audits has started.

The 2003 management review gave rise to some action points but concluded that so far the introduction of the system had been very successful.

Liaison with ILAC and ISO: During the last year, it has become evident that we need to maintain a closer liaison with ILAC and ISO. In particular, we have begun an open exchange of information with ISO and now are represented at the major meetings of the REMCO and CASCO committees. The BIPM now also takes a more active role in a number of ISO working groups, namely on vocabulary, quality in metrology and accreditation issues. The aim is to represent the Metre Convention's position *vis-à-vis* ISO activity, and to alert NMIs and others on any work at ISO which may have an impact on them or the activities of the Convention.

We have also set up a formal joint working group with ILAC in support of the BIPM-ILAC Memorandum of Understanding. The group met in March 2004 at the BIPM. As a result, both organizations will prepare a joint paper on fundamental issues concerning traceability to the SI, and the national and regional roles and responsibilities of NMIs and NABs, reflecting changes in these roles which arise especially from economic pressures. This close collaboration between the two organizations is aimed at dealing with a number of practical issues aimed at improving the effectiveness and transparency of "national measurement systems" which combine the responsibilities of NMIs and accredited laboratories.

1.2 Publications, lectures and travel of the Director

1.2.1 External publications

1. Wallard A.J., Collaboration between BIPM and ILAC - an update, *Proc. 2003 NCSLI International Annual Workshop and Conference* (Tampa, Florida, United States), 2003, 7 pp.
2. Wallard A.J., Traceability issues in measurement, *Accred. Qual. Assur.*, 2003, **8**, 319-322.
3. Wallard A.J., News from the BIPM – 2003, *Metrologia*, 2004, **41**, 99-108.

1.2.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- London (United Kingdom), 10 July 2003, for a meeting of the Royal Society Paul Fund;
- Panamá (Rep. of Panamá), 15-17 September 2003, for the General Assembly of SIM;
- Paris (France), 22 September 2003, at the Académie des Sciences for a meeting of the Working Group of the Académie on base units of the SI;
- Berlin (Germany), 26 September 2003, for the 50th anniversary of the Berlin PTB;
- Birmingham (United Kingdom), 1 October 2003, to give the Poynting Lecture at the University of Birmingham;
- London (United Kingdom), 20 October 2003, to receive the Tompion Gold Medal of the Worshipful Company of Clockmakers;
- London (United Kingdom), 21 October 2003, for a meeting of the Royal Society Paul Fund and editorial board of *Notes and Records*;
- São Paulo (Brazil), 4-6 November 2003, to lecture at a Metrology Symposium organized by INMETRO;
- Singapore (Rep. of Singapore), 2-5 December 2003, for the General Assembly of the APMP.

A.J. Wallard to:

- San Diego (United States), 31 July – 4 August 2003, for a meeting of the CCL Working Group on Dimensional Metrology;
- Tampa (Florida, United States), 17-21 August 2003, for the NCSL International (NCSLI) annual workshop and symposium;
- Bratislava (Slovakia), 20-22 September 2003, to the General Assembly of ILAC;
- London (United Kingdom), 31 September – 1 October 2003, and 10 March 2004, to chair the Institute of Physics Membership and Qualifications Board;
- Turin (Italy), 27-28 October 2003, for a meeting of the Scientific council of the IEN;
- Aberystwyth (United Kingdom), 11-12 November 2003, to deliver an inaugural lecture as visiting professor at the University of Wales;

- Geel (Belgium), 20-21 November 2003, at the IRMM, as part of the Review Committee of the Joint Research Centre;
- London (United Kingdom), 25 November 2003, to the Professional Standards Committee of the Institute of Physics;
- Brussels (Belgium), 8-9 December 2003, for the final meeting of the Joint Research Centre Review Committee;
- Braunschweig (Germany), 14-15 December 2003, for a presentation in honour of Dr Helmcke at the PTB;
- Monterey (United States), 14-17 January 2004, NCSLI Board of Management;
- London (United Kingdom), 22-23 January 2004, to the IOP;
- Paris (France), 2 February 2004, at the Paris Observatory;
- London (United Kingdom), 9 February 2004, at the NPL and Rank Prize Fund dinner;
- Braunschweig (Germany), 25-26 February 2004, to visit A. Bryden at the PTB;
- Geneva (Switzerland), 27 February 2004, for a meeting at ISO with A. Bryden;
- Washington DC (United States), 19 April 2004, for a presentation at the NIST;
- Columbia (Maryland, United States), 20 April 2004, to the ILAC/NIST forum on government acceptance of test data;
- London (United Kingdom), 28 April 2004, to a meeting of the IOP Council;
- Querétaro (Mexico), 3-4 May 2004, to the JCRB;
- Bled (Slovenia), 2 June 2004, to the 18th General Assembly of EUROMET;
- Vienna (Austria), 10 June 2004, at the UNIDO;
- Genova (Italy), 14 June 2004, for an invited lecture at the 2nd International Symposium on Measurement, Analysis and Modelling of Human Functions;
- London (United Kingdom), 28 June 2004 and 1-2 July 2004, to the CPEM;
- Geneva (Switzerland), 29-30 June 2004, to the WTO.

1.3 Activities of the Director related to external organizations

During the period July to December 2003, Dr Quinn was a member of the Advisory Board of the NRC-INMS, the CODATA Task Group on Fundamental Constants, the IUPAC's Interdivisional Committee on Terminology, Nomenclature and Symbols, the WHO Expert Committee on Biological Standards and the Académie des Sciences (Paris) working group on base units and fundamental constants. He was Chairman of the Royal Society Paul Fund, the JCRB and the JCGM.

The current Director, Professor Wallard, is a member of the Scientific Councils of the IMGC and the IEN, Turin; he replaced Dr Quinn as a member of IUPAC's Interdivisional Committee on Terminology, Nomenclature and Symbols; and is a member of IUPAP-C.2 Commission on symbols, units, nomenclature, atomic masses and fundamental constants. He is a member of the external advisory panel of the University of Wales at Aberystwyth and a Visiting Professor in the Institute of Mathematics and Physical Sciences; Vice President for Membership and Qualifications of the Institute of Physics (IOP, United Kingdom), a member of IOP Council, Chair of its Membership and Qualifications Board and a member of its Professional Standards Committee; a member of the Board of the National Conference of Standards Laboratories International (NCSLI); a member of the Scientific Academy of Turin; and replaced Dr Quinn as Chairman of the NEWRAD scientific committee, the JCRB and the JCGM.

2 LENGTH (A.J. WALLARD)

2.1 Traveling comb and comb comparisons
(L.-S. Ma, L. Robertsson and M. Zucco)

During the year, we completed the construction of a traveling comb and have used it in two international comparisons: a bilateral one at the BIPM and a trilateral at NIST which also involved a comb from East China Normal University (ECNU). The frequency agreement among three of the combs (BIPM-C1, BIPM-C2 and ECNU-C1), when referenced to a hydrogen maser, is at the sub-hertz level for frequency measurements in the 563 THz range. When the combs are referenced to an optical standard, the frequency

agreement among four combs (BIPM-C2, ECNU-C1, NIST-BB1 and NIST-BB2), is much improved and found to be at the 10^{-19} level in the frequency range 333 THz-456 THz. The results have been published in *Science* and attracted considerable attention from the scientific community.

2.2 Absolute frequency measurements and the BIPM key comparison BIPM.L-K11 (L.-S. Ma, L. Robertsson and M. Zucco)

Since early 2002, we have provided absolute frequency measurements with our comb systems. At present, the measurements are arranged in two campaigns per year. During the last year, standards from BNM-INM (France), CSIR (South Africa), IMGC (Italy), INTI (Argentina), IPQ (Portugal), MIKES (Finland), NIS (Egypt) and VNIIM (Russian Fed.) have participated. In total, 29 lasers have been measured at wavelengths 515 nm, 532 nm, 543 nm and 633 nm. Absolute frequency measurements provide an improvement of about a factor of 5 for 633 nm standards through the method (b) in the *Mise en Pratique* (MeP) as compared to the method (c). This is essentially due to the fact that the possible frequency shifts caused by impurities in the iodine cell no longer need to be included in the uncertainty budget. The improvement does not result simply from the comb technique itself, but from its systematic application to the lasers we have measured. This work will now continue under the new key comparison, BIPM.L-K11, initiated during the 11th meeting of the CCL in 2003.

The BIPM.L-K11 key comparison essentially concerns those wavelengths in the list of recommended radiations, which are used in the field of dimensional metrology. Typical examples would be the 532 nm, 543 nm, 612 nm and 633 nm iodine-stabilized standards but in due course it may be useful to include others. BIPM.L-K11 therefore provides a much wider coverage than BIPM.L-K10 which took only the 633 nm standards into consideration. The CCL also proposed the inclusion of absolute frequency measurements, matrix measurements as well as direct frequency heterodyne measurements in which only the difference in frequency between two standards is measured. As a key comparison, BIPM.L-K11 will not only provide better estimates of the frequencies listed in the MeP but also extend the ways in which participants can claim and demonstrate traceability to the definition of the metre. The BIPM.L-K10 had the form of an ongoing BIPM comparison; however, for BIPM.L-K11, whilst a considerable number of the measurements are likely to be made at the BIPM, other frequency measurements – absolute as well as heterodyne – are expected to be made in

regional comparisons. The inclusion of regional heterodyne measurements in the comparison is, of course, an effective way of reaching a large number of laboratories in the RMOs.

2.3 Laser standards at 633 nm and 532 nm
(L.-S. Ma, L. Robertsson and M. Zucco)

BIPM4 and BIW167 are maintained at the BIPM and provide our realization of the definition of the metre at 633 nm. A regular calibration of these standards provides us with permanent traceability to the SI metre in case there is a failure of the comb during a measurement campaign.

The frequency of the new 532 nm Nd:YAG laser standard, Nd:YAG-C, was measured. By substracting the carrier offset frequency f_o from the beat between the comb and the laser standard, the control of the comb is reduced to a one dimensional problem, i.e. only the repetition rate needs to be phase looked to the time base used. The frequency, f, found for the a_{10} component in the R(56)32-0 transition was

$$f = 563\ 260\ 223\ 510.4 \text{ kHz}.$$

This value is remarkably close to the frequency of the two other 532 nm standards of the BIPM, the Nd:YAG-A and Nd:YAG-B, with frequencies 563 260 223 510.8 kHz and 563 260 223 510.85 kHz, respectively. When using the same spectroscopic parameters, a reproducibility of only some few hundred hertz is found.

2.4 Iodine cells (L. Robertsson and M. Zucco; J. Labot)

The BIPM continues to offer a service for the filling and testing of iodine cells used in stabilized lasers and spectroscopy. These cells are offered to NMIs and other suitable customers on repayment. In the last year, a total of 17 cells have been sold.

The in-house capabilities have been extended to allow filling of cells up to 1.8 m long. The aim of this effort is to improve the stability of the BIPM's Nd:YAG laser systems and provide a more stable molecular reference for the comb work.

A new laser at 633 nm has been constructed and is dedicated to the testing of the iodine cells and to research. In this laser, it is easier to insert the iodine cell and to include a means of controlling the rotation and displacement of

the iodine cell as well as the He-Ne tube. At present, this laser has a lower mechanical stability than the compact Invar structure and therefore requires a longer integration time to obtain the same level of statistical uncertainty. Studies are underway to implement a complete digital control of the system.

The quality of the cell is characterized by measuring the absolute frequency of the laser locked to the f component. If the measured frequency is within 5 kHz with respect to the CCL value, then the cell is regarded as meeting the highest standards of quality and performance.

Studies are also underway on the characterization of the quality of the cells by measuring the sensitivity coefficients of the working parameters. This approach has the advantage that it only requires the use of a stable rather than an absolute reference.

The complementary testing procedure of iodine cell quality by means of laser induced fluorescence has been rebuilt. In addition to experimental modifications, new software has been developed which controls the system, acquires and analyzes the data and saves the final results in a report.

2.5 **Methane-stabilized He-Ne lasers at $\lambda \approx 3.39$ μm using internal and external cells** (R. Felder; D. Rotrou)

2.5.1 Maintenance of lasers

The construction and study of He-Ne laser tubes and methane cells continues with the aim of completing an absolute frequency measurement using the femtosecond comb system. Two Brewster-end CH_4 cells have been modified and are being processed in our new programmable furnace. We have recently received new laser tube glassware which have been delivered to a company for molecular bonding of the end-windows.

2.5.2 Measurement of the absolute frequency of the reference laser BIDM1

The heterodyne laser BIDM1 is now operating with two He-Ne tubes in series in the cavity.

A heterodyne laser and a reference two-mode laser are under construction for the independent running of the two-mode second telescopic laser (Tel-100).

VB, the BIPM one-mode laser reference which was used in the past in several experiments of absolute frequency determination with conventional frequency-chains has been re-built.

The experimental set-up will operate with two independent two-mode lasers, VB and the powerful heterodyne laser for injection into a frequency mixing crystal via an optical fiber link to the comb laboratory. This set-up is also designed to provide us with the ability to calibrate 3.39 μm frequency standards from NMIs against our comb-generator.

2.6 **Dimensional metrology** (L.F. Vitushkin and O.A. Orlov*)

2.6.1 Laser interference diffractometer

The new CCD camera was installed and the FRINGER software for the measurements of the period of interference fringes was modified. A new optical system is under investigation. The new holographic gratings of the type BIPM-HOLOGRATE with various conductive coatings have been fabricated.

2.6.2 Iodine-stabilized diode-pumped solid-state lasers for dimensional metrology and absolute gravimetry

The servo electronics, laser head and shape of the iodine cell of the compact iodine-stabilized diode-pumped solid-state Nd:YVO_4/KTP laser at 532 nm with the third harmonics stabilization have been modified. Investigations of the laser were undertaken at the BIPM and showed an improved performance.

New optical elements, photo detector board and electronics are under development to perform the measurements of free-fall acceleration in the FG5-108 ballistic gravimeter using a compact Nd:YVO_4/KTP/I_2 laser at 532 nm.

The Yb:KGW/KTP/I_2 laser at 515 nm has been modified and its performance studied at the BIPM.

2.7 **Gravimetry** (L.F. Vitushkin)

The absolute gravimeter FG5-108 was repaired by Micro-g Solutions (Eirie, United States). The regular measurements of a free-fall acceleration *g* at the site A of the BIPM were started. Current results coincide, within the

* VNIIM, St Petersburg (Russian Fed.).

uncertainty of the measurements, with the mean value of g obtained in the measurements from the period 1997 to 2001.

The design of a new dropping chamber for an absolute ballistic gravimeter was begun in collaboration with the Mendeleyev Institute for Metrology (VNIIM).

The first joint meeting of the CCM working group on gravimetry and the Study Group on Comparison of Absolute Gravimeters of the IAG was organized at the BIPM on 26-27 May 2004.

2.8 Publications, lectures, travel: Length section

2.8.1 External publications

1. Ma L.-S., Bi Z., Bartels A., Robertsson L., Zucco M., Windeler R.S., Wilpers G., Oates C., Hollberg L., Diddams S.A., Optical Frequency Synthesis and Comparison with Uncertainty at the 10^{-19} Level, *Science*, 2004, **303**, 1843-1845.
2. Ma L.-S., Picard S., Zucco M., Chartier J.-M., Robertsson L., Direct measurement of the absolute frequency of the international reference laser BIPM4, *Metrologia*, 2004, **41**, 65-68.
3. Ma L.-S., Robertsson L., Picard S., Zucco M., Bi Z., Wu S., Windeler R.S., First international comparison of femtosecond laser combs at the International Bureau of Weights and Measures, *Opt. Lett.*, 2004, **29**, 641-643.
4. Ma L.-S., Robertsson L., Zucco M., Bi Z., Windeler R.S., Bartels A., Wilpers G., Oates C., Hollberg L., Diddams S.A., Precision Test of Femtosecond Laser Optical Frequency Synthesizers, *Conference on Lasers and Electro Optics (CLEO) Digest*, San Francisco, United States, 16-21 May 2004, CMW6, 2 pp.
5. Ma L.-S., Zucco M., Picard S., Robertsson L., Windeler R.S., A new method to determine the absolute mode number of a mode-locked femtosecond laser comb used for absolute optical frequency measurements, *IEEE J. Select. Top. Quant. Electr.*, 2003, **9**, 1066-1071.
6. Madej A., Bernard J.E., Robertsson L., Ma L.-S., Zucco M., Windeler R.S., Long-term absolute frequency measurements of 633 nm iodine-stabilized laser standards at NRC and demonstration of high reproducibility of such devices in international frequency measurements, *Metrologia*, 2004, **41**, 152-160.

7. Vitushkin L.F., Krivtsov E.P., Sinelnikov A.E., Development of a metrology and the limits in the measurements in geophysics, *Problems of Geophysics in XXIst Century*, Edit. Nauka, 2003, **2**, 245-265 (in Russian).

2.8.2 Travel (conferences, lectures and presentations, visits)

R. Felder to:

- Fichou, Fresnes (France), 19 November 2003, for control and reception of He-Ne laser tubes, and 7 May 2004, for delivery of laser-tube glasses to be processed;
- CNRS, Verrières (France), 21 November 2003, for future collaboration.

L.-S. Ma to:

- NIST (United States), 1 July – 1 September 2003, to work on the comparison between ECNU-NIST and BIPM combs;
- JILA and NIST (United States), 1 February – 30 April 2004, for collaboration.

L.-S. Ma, L. Robertsson and M. Zucco to the CPEM 2004, London (United Kingdom), 28 June to 2 July 2004, posters:

- "International comparison of transportable femtosecond laser frequency comb", by L.-S. Ma, Z. Bi, A. Bartels, L. Robertsson, M. Zucco, R.S. Windeler, G. Wilpers, C. Oates, L. Hollberg and S.A. Diddams, *CPEM 2004 Digest*, pp. 14-15.
- "Absolute frequency measurement and comparison of the UME and the BIPM He-Ne/I_2 lasers", by R. Hamid, E. Sahin, M. Celik, M. Zucco, L. Robertsson and L.-S. Ma, *CPEM 2004 Digest*, pp. 261-262.
- "A frequency doubled amplified-fiber laser for molecular iodine spectroscopy near 515 nm", by J.-P. Wallerand, P. Juncar, T. Badr, L. Robertsson, L.-S. Ma and M. Zucco, poster presented by J.-P. Wallerand.

L. Robertsson to the NMIJ/AIST (Japan), 31 January – 7 February 2004, as auditor.

L.F. Vitushkin, 9-14 and 22-26 March 2004, St Petersburg (Russian Fed.), to participate in the discussions on the modification of the laser electronics and a new dropping chamber of an absolute gravimeter at the VNIIM.

M. Zucco to the NIST (United States), 7-14 July 2003, to work on the comparison between ECNU-NIST and BIPM combs.

2.9 Activities related to the work of Consultative Committees

Members of the Section attended meetings of the CCL, the Joint Working Group CCL/CCTF.

R. Felder is the Executive Secretary of the CCL, working with A.J. Wallard. He is also joint Secretary to the Joint Working Group CCL/CCTF.

L.F. Vitushkin is Chairman of the CCM Working Group on Gravimetry and of a Study Group on Comparison of Absolute Gravimeters within the Commission 2 "Gravity field" of the IAG and is Moderator of Discussion Group 7 on Nanometrology of the CCL WGDM.

2.10 Visitors to the Length section

- Dr J.-P. Wallerand (BNM-INM), 22 and 30 July 2003, 1 August 2003, 30 March 2004, and 8-18 June 2004.
- Dr M. Pisani (IMGC-CNR), 30 July 2003.
- Dr M. Gubin (Lebedev Institute), 8 and 10 September 2003.
- Dr A. Onae (NMIJ/AIST), 8 and 12 September 2003, and 30 March 2004.
- Dr H. Matsumoto (NMIJ/AIST), 10 September 2003.
- Dr M. Merima and Dr K. Nyholm (MIKES), 24-28 November 2003.
- Dr T. Conjo (INTI), 24-28 November 2003.
- Dr P. Cordiale (IMGC-CNR), 27 November 2003.
- Dr M.P. Sassi and Dr E. Malgeri (IMGC-CNR), 28 January 2004.
- Dr A. Clairon (BNM-SYRTE), 30 March 2004.
- Dr Y. Domnin (VNIIFTRI), 30 March and 2 April 2004.
- Dr R. Hamib (UME), 30 March and 2 April 2004.
- Dr A. Godone (IEN), 1 April 2004.
- Mr P. Plombin (Ets. Dumas, Noizay, France), 22 April and 3 May 2004.
- Dr P. Juncar (BNM-INM), 5 May 2004.
- Mr F. Senotier (Laserlabs, Étampes, France), 13 May 2004.

- Dr P. Medvedev, Dr E. Boyarsky and Dr L. Afanasieva (IPE RAS), and Dr E. Krivtsov (VNIIM), 28 May 2004, for the discussion on the project of a new absolute gravimeter.
- Dr N. Medvedeva (IPE RAS), 2 June 2004, to acquaint with the organization of absolute measurements of free-fall acceleration at the BIPM.

2.11 Guest workers

- Dr O.A. Orlov (VNIIM), 31 August – 26 November 2003.
- Dr F. Saraiva (IPQ), 8-14 May 2004.
- Dr O. Terre (NIS), 7-19 May 2004.
- Dr L. Moster (CSIR), 10-15 May 2004.
- Dr K. Chekirda, Dr V. Fedorin and Dr Yu. Zackarenko (VNIIM), 10-17 May 2004.
- Dr T. Niebauer (Micro-g Solutions, United States), 24–28 May 2004, to check the absolute gravimeter FG5-108 of the BIPM.
- Dr S. van den Bergh (NMi), 7-25 June 2004.

3 MASS AND RELATED QUANTITIES (R.S. DAVIS)

3.1 Calibrations (R.S. Davis; J. Coarasa)

During the past year, certificates were issued for the following 1 kg prototypes (in platinum-iridium): No. 38 (Switzerland), No. 53 (Netherlands), No. 65 (Slovakia), No. 82 (United Kingdom). In addition, six new prototypes have been fabricated by the BIPM machine shops and studied by the Mass section. The first of these, No. 86 has been allocated to Sweden. Three others will be allocated later this calendar year, to Australia, Mexico and Switzerland. Two will remain with the BIPM in order to replace prototypes Nos. 9 and 31 (see below). Note that one replacement prototype was already foreseen in last year's report.

The stackable disk of 1.1 kg in Pt/Ir, mentioned in last year's report, is well along in its fabrication.

Much additional work has also gone into maintaining the calibration of our own working standards in Pt/Ir. Whereas in the past we have relied heavily on prototypes Nos. 9 and 31 as working standards, we are currently using prototype No. 63 and standard No. 42'. Statistical controls showed that the masses of Nos. 9 and 31 were no longer sufficiently stable. These prototypes were cleaned and washed. We are currently monitoring the evolution in their mass.

Certificates for 1 kg standards in stainless steel were issued to the NMIJ/AIST (Japan) and SIRIM Berhad (Malaysia). We have also carried out additional mass determinations to support the programme of work for the FB-2 balance.

Our HK1000MC balance was repaired by the manufacturer to correct erratic performance. Such an intervention involves a considerable number of preliminary measurements before the repair, which was needed to determine the exact nature of the problem, and then a careful study subsequent to the repair to ensure that there is no discontinuity in the performance.

In May 2004, we noted a serious problem with the determination of air density within both 1 kg comparators used for calibrations. Finding the source of the problem has been challenging and, of course, no calibration work can be done until the difficulty is resolved.

3.2 Hydrostatic weighing apparatus

(R.S. Davis and C. Goyon-Taillade)

The hydrostatic weighing apparatus is used to determine the density of mass standards, in particular new prototypes manufactured at the BIPM.

Densities were determined for Pt/Ir samples destined to become 1 kg prototypes Nos 90 and 91. In addition, the density of a 500 g standard in Pt/Ir was determined. This and two similar standards are part of a special order. A great number of internal checks were also carried out in the course of these measurements.

With the help of the NMIJ/AIST (Japan) we are in the process of acquiring two 500 g cylinders of single-crystal silicon. It is intended that, once calibrated by the NMIJ/AIST, these can serve as reference standards for density as determined by hydrostatic weighing.

Work on this project was suspended from January to June 2004 due to the leave of absence of C. Goyon-Taillade.

3.3 **Water vapour sorption on mass standards** (H. Fang and A. Picard)

We recall that the aim of this work is to study water vapour sorption effect on mass standards. We have carried out measurements on stainless steel, Pt/Ir and silicon samples by both gravimetry and ellipsometry.

Additional investigations were carried out by means of ellipsometry. A special Pt/Ir disk was used to test water sorption effects as a function of the polishing procedure. One of the flat surfaces was polished by single-point diamond machining and the second by polishing with diamond paste, a technique recently adopted at the BIPM for fabrication of new prototypes. Results showed that the sorption effects were about two times smaller for the surface polished using diamond paste than for that produced by diamond machining. The sorption effect was also measured on three gold samples: a pure gold cylinder belonging to METAS, a glass plate and a copper disc both coated with gold.

Results obtained with the METAS mass and the glass sample coated with gold showed a desorption of about 0.1 nm from air to *vacuum* and at relative humidity, h, equal to 0.5, an adsorption coefficient of about 0.2 nm/h in the range of $0.35 < h < 0.70$. The sorption effect was slightly higher for the copper sample coated with gold which could, perhaps, be explained by the fact that the gold coated on the surface can diffuse into the copper.

Collaboration between the NPL and the BIPM is planned to investigate the sorption effects on silicon in the framework of the Avogadro project. In fact, the sorption effects already obtained at the NPL were more than five times larger than those measured at the BIPM. The plan is to elucidate the source of this difference by exchanging sorption artefacts.

3.4 **FB-2 flexure-strip balance** (H. Fang and A. Picard)

3.4.1 *Vacuum* study for prototype No. 85

As mentioned above, the NIST has taken delivery of a new 1 kg prototype, No. 85. At the request of NIST, we have carried out a short study of the mass stability of this standard in going from air to *vacuum*. This study is separate from the calibration, which was carried out in the usual way and which was repeated after the *vacuum* study.

3.4.2 Verifications

The effects due to carrousel position, the magnetic dampers and the water circulation system (for the thermal stability within the balance enclosure) were evaluated by means of mass comparisons between two 1 kg stainless steel masses. The error related to the carrousel position was estimated by comparing the mass differences between the two masses, placed successively at different carrousel positions. The position errors were all within 2 µg in either air or *vacuum*.

To confirm the small influence of the magnetic dampers on the masses in the balance or on the balance itself, a comparison in air between two 1 kg stainless steel mass standards (volume magnetic susceptibility, χ, of 0.0033 with a remanence < 0.1 µT) was carried out with and without the magnetic dampers. The change of the mass difference between the two objects was about 0.2 µg (s = 0.1 µg) between the two results. However, the standard deviation of the results obtained without magnetic dampers was about two times larger than those measured with the magnetic dampers.

The FB-2 balance is equipped with a double enclosure through which water of constant temperature is circulated. This feature is useful for special studies such as water sorption effects on mass standards between air and *vacuum* conditions, because temperature stability after the changing of pressure conditions is reached more quickly. A small study was carried out to check the consequence on the weighings due to the thermal regulation of the enclosure. Mass comparisons carried out with or without thermal regulation were identical. However, due to dynamic control of the circulating water, the short-term stability of weighings is inferior to that obtained without control (that is, passively).

3.4.3 Modification

In anticipation of our commitments to the Avogadro project, the balance has been modified to permit the comparison of a 1 kg silicon sphere (Ø = 94 mm) against a 1 kg Pt/Ir prototype (Ø = 39 mm) in either air or in *vacuum*. To accept so large a diameter, the columns supporting the balance were removed and modified. Additional mass supports manufactured by the BIPM workshop are placed between the masses and the pan in order to increase the height of the masses above the carrousel.

3.5 **Humidity generator** (A. Picard and N. Depouez*)

As was mentioned in last year's report, the BIPM has developed a humidity generator for accurate in-house calibrations of dew point meters or humidity sensors. The generator is composed of two humidity saturators placed in separated thermo-regulated baths. The desired dew point temperature is obtained by adjustment of the air temperature inside the saturators. The generator is now operational and the combined standard uncertainty of the dew point temperature calibration is 0.06 °C in the range from 5 °C to 15 °C. The measurements carried out this year agree to within 0.01 °C with those obtained last year, which confirms the excellent reproducibility of the generator. In the coming year, we plan to introduce this system of humidity calibration into the Quality System.

3.6 **Magnetic properties of mass standards** (R.S. Davis)

Accessories and software to realize the BIPM susceptometer have been provided to the NIM (China) and the NML-CSIRO (Australia). This year, we have added a service to certify the volume magnetic susceptibility of samples suitable for calibrating the susceptometer. The new service has been added to the BIPM Quality System and, to date, five calibration certificates have been issued.

We have participated in an international comparison of the volume magnetic susceptibility and magnetic remanance of three 1 kg mass standards. The comparison has been organized by the NRC (Canada), which is also piloting the exercise. The first petal (comprising 12 participants) has been completed. All participants use a version of the BIPM susceptometer.

3.7 **Pressure** (A. Picard)

Calibrations of pressure gauges with respect to the BIPM mercury manobarometer, as specified in the BIPM Quality System, were performed until December 2003. A serious malfunction of this device occurred in January 2004, which put our primary pressure reference out of service. Due to the very high cost of repairing the manobarometer (which has been operated for the last 32 years), we have decided to replace it by a primary pressure balance. This instrument is easier to operate but will, nevertheless,

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* Student.

allow us to calibrate secondary pressure gauges to within the needed uncertainty (0.5 Pa). We took delivery of the pressure balance at the BIPM in June 2004. A geometric calibration of the piston-cylinder has been planned.

3.8 *G*, torsion balance

(R.S. Davis, H.V. Parks*, T.J. Quinn and C.C. Speake**)

The new apparatus is now operating extremely well in both the servocontrolled and free-deflection modes. All data-acquisition is automated. Although the standard deviation and reproducibility of results has reached our target, we are still taking data and thus have yet to calculate a new value of *G*. The present status of the experiment was reported in June 2004 at the CPEM in London.

Progress this year was greatly aided by the calibration and detailed study of our autocollimator. This was carried out by A. Just and R. Probst of the PTB. Their research shows that the ratio of signal to noise is not improved by angle multiplication. We have also benefited from analyses of the noise in our data carried out by our colleague T.J. Witt. This permits us to spend less measurement time to reach the same uncertainty.

3.9 Publications, lectures, travel: Mass section

3.9.1 External publications

1. Davis R.S., The SI unit of mass, *Metrologia*, 2003, **40**, 299-305.
2. Davis R.S., Gläser M., Magnetic properties of weights, their measurements and magnetic interactions between weights and balances, *Metrologia*, 2003, **40**, 339-355.
3. Davis R.S. *et al*., Final report on CIPM key comparison of 1 kg standards in stainless steel (CCM.M-K1), *Metrologia*, 2004, **41**, *Tech. Suppl.,* 07002.
4. Davis R.S., Erratum: Determining the Magnetic Properties of 1 kg Mass Standards, *J. Res. Natl. Inst. Stand. Technol.*, 2004, **109**, 303.
5. Picard A., The BIPM flexure-strip balance FB-2, *Metrologia*, 2004, **41**, 319-329.

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* JILA, as of 1 January 2004.
** University of Birmingham (United Kingdom).

6. Picard A., Fang H., Mass comparisons using air buoyancy artefacts, *Metrologia*, 2004, **41**, 330-332.

7. Picard A., Fang H., Methods to determine water vapour sorption on mass standards, *Metrologia*, 2004, **41**, 333-339.

8. Silvestri Z., Davis R.S., Genevès G., Gosset A., Madec T., Pinot P., Richard P., Volume magnetic susceptibility of gold-platinum alloys: possible materials to make mass standards for the watt balance experiment, *Metrologia*, 2003, **40**, 172-176.

3.9.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- BNM-LNE, Paris (France), 30 June – 1 July 2003, to attend the watt balance technical meeting, accompanied by H. Fang and A. Picard;
- NIST, Gaithersburg MD (United States), 11-14 August 2003, to meet with personnel involved with mass metrology (both primary and legal), fluid flow and the NIST watt balance;
- Tampa (Florida, United States), 17-20 August 2003, to attend the NCSL International Annual Workshop and Symposium. This travel was at the invitation of the NIST Weights and Measures Division, Laboratory Metrology Group, which had organized a session on "Magnetism in Mass Measurement". A paper was also presented at the Workshop and Symposium: "Magnetization of Mass Standards as Determined by Gaussmeters, Magnetometers and Susceptometers";
- NPLI, New Delhi (India), 12-16 January 2004, to carry out a peer review of calibration services in the area of mass and density;
- NPL, Teddington (United Kingdom), 4 March 2004, to attend a meeting of the NPL Watt Balance Design Review Group;
- CENAM, Querétaro (Mexico), 10-14 May 2004, to carry out a peer review of calibration services in the area of mass and density;
- NPL, Teddington (United Kingdom), 26 June 2004, to attend the CCEM workshop on monitoring the stability of the kilogram; 27 June, to attend a meeting of the CCM Working Group on the Avogadro Constant (CCM WGAC), accompagnied by A. Picard.

On 7 July 2003, R.S. Davis gave an interview to Mrs C. Bonneau (*Science et Vie*) about the international prototype of the kilogram (Le kilogramme n'est plus ce qu'il était !, *Science et Vie*, Sept. 2003, 96-100).

A. Picard to:

- BEV, Vienna (Austria), 23-26 February 2004, to attend the EUROMET mass contact persons meeting;
- Sartorius, Göttingen (Germany), 22-23 March 2004, to present the BIPM watt balance project in order to fix our requirements for the weighing cells lend by the Sartorius company, accompanied by R.S. Davis;
- Technische Universität, Ilmenau (Germany), 23-24 March 2004, to give technical support on the collaboration with the Sartorius company, accompanied by R.S. Davis;
- CEDRAT, Grenoble (France), 7 April 2004, to present our requirements for the magnet circuit of the BIPM watt balance project in order to have a contract with the company for this particular development, accompanied by R.S. Davis and M. Stock (see also 11.3);
- NIST, Gaithersburg (United States), 12-13 May 2004, to visit the Mass section and the NIST watt balance laboratory as well as to have discussions with the watt balance team, accompanied by M. Stock (see also 11.3).

3.10 Activities related to the work of Consultative Committees

R.S. Davis is Executive Secretary of the CCM which, with the recent addition of the former *Ad-hoc* Working Group on Viscosity, now has working groups in 11 technical areas.

A. Picard maintains a website, created in September 2001 at the BIPM that facilitates the work of the CCM Working Group on the Avogadro constant. He is the contact person for mass in the framework of the CCM Working Group on the Determination of the Avogadro Constant.

3.11 Other activities

R.S. Davis was a faculty member of the BIPM Summer School, 21 July −1 August 2003.

R.S. Davis is one of two external members of the NPL Watt Balance Experiment Design Review Group.

3.12 Visitors to the Mass section

- Dr M. Gläser (PTB), 4 July 2003 and 20-21 November 2003.
- Ms E. Funes, Mr C. Aramburo, Mr O. Purata (CIATEC, Mexico), 29 September 2003.
- Mr J.-C. Legras (BNM-LNE), 28 October 2003.
- Mr S. Downes and Mr D. Bayliss (NPL), Dr P. Pinot (BNM-INM), 17 November 2003.
- Dr R. Probst and Dr A. Just (PTB), 2 December 2003.
- Prof. J. Luo and Dr Z. Li (HUST), 26 January 2004.
- Mr T. Petelski and Mr M. Fattori (Physics Department, University of Florence), 19 February 2004.
- Mr U. Jacobsson (SP), 26-28 May 2004.

3.13 Guest workers and student

- Mr S. Mizushima (NMIJ/AIST), 3-27 November 2003.
- Dr H. Parks (JILA), 5-16 March 2004.
- Mr N. Depouez (IUT Orsay), 5 April to 25 June 2004.

4 TIME (E.F. ARIAS)

4.1 International Atomic Time (TAI) and Coordinated Universal Time (UTC) (E.F. Arias, J. Azoubib*, Z. Jiang, W. Lewandowski, G. Petit and P. Wolf; H. Konaté, M. Thomas** and L. Tisserand)

The reference time scales TAI and UTC are computed from data reported regularly to the BIPM by the timing centers that maintain a local UTC; monthly results are published in *Circular T*. The *Annual Report of the BIPM Time Section (2003),* Volume **16**, complemented by computer-readable files on the BIPM home page (www.bipm.org), provides the definitive results for 2003.

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* Until his retirement on 30 September 2003.
** Until her retirement on 30 September 2003.

4.2 Algorithms for time scales

(J. Azoubib, W. Lewandowski, G. Petit and P. Wolf)

The algorithm used for the calculation of time scales is an iterative process that starts by producing a free atomic scale (EAL) from which TAI is derived. Research concerning time scale algorithms is conducted at the Time section with the aim of improving the long-term stability of EAL and the accuracy of TAI.

4.2.1 EAL stability

Some 85 % of clocks are now either commercial caesium clocks of the HP/Agilent 5071A type or active auto-tuned hydrogen masers. To improve the stability of the free atomic scale (EAL), the weighting procedure applied to clocks sets the maximum relative weight each month to 2.5/N, where N is the total number of participating clocks. In this way, we have substantially reduced the number of the clocks at the maximum weight (13 % in average over year 2003, against 54 % in year 2000). We allow a clock to reach the maximum weight when its variance computed from 12 consecutive 30 day samples is, at most, 5.8×10^{-15} (15.9×10^{-15} in the previous weighting procedure). This procedure generates a time scale which relies upon the very best clocks.

The medium-term stability of EAL, expressed in terms of an Allan deviation, is estimated to be 0.6×10^{-15} for averaging times of 20 to 40 days over the period January 1999 to June 2004.

4.2.2 TAI accuracy

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from the SI second as produced on the rotating geoid by primary frequency standards. Since July 2003, individual measurements of the TAI frequency have been provided by nine primary frequency standards including five caesium fountains (IEN-CSF1, NIST-F1, PTB CSF1, SYRTE-FOM and SYRTE-FO2). Reports on the operation of the primary frequency standards are regularly published in the *Annual Report of the BIPM Time section*.

A steering of the frequency of TAI of 1.0×10^{-15} has been applied every two months to put the TAI scale unit in conformity to the SI second. Since July 2003, the global treatment of individual measurements has led to a relative

departure of the duration of the TAI scale unit from the SI second on the geoid ranging from $+0.5 \times 10^{-14}$ to $+1.19 \times 10^{-14}$, with a standard uncertainty of 0.2×10^{-14}. These values indicate that the scale unit of TAI has significantly deviated from its definition, and that the steering procedure is in need of revision. This has been recognized by the CCTF in its Recommendation CCTF 3 (2004). Consequently, starting in July 2004, a monthly steering correction of magnitude up to 0.7×10^{-15} will be applied.

4.2.3 Independent atomic time scales

The BIPM staff have been involved in the organization and elaboration of the Polish independent atomic time scale TA(PL). Specially devised software for a limited number of clocks has been developed, and is being improved. For an averaging time of about one month the stability of TA(PL) is approximately 2.5×10^{-15}.

TT(BIPM)

Because TAI is computed in "real-time" and has operational constraints, it does not provide an optimal realization of Terrestrial Time TT, the time coordinate of the geocentric reference system. The BIPM therefore computes another realization TT(BIPM) in post-processing, which is based on a weighted average of the evaluations of TAI frequency by the primary frequency standard (PFS). The procedures to process PFS data have been recently updated and we have, consequently, provided an updated computation of TT(BIPM), named TT(BIPM2003). In this, we use all recently available data from new caesium fountains and a revised estimation of the stability of the free atomic time scale EAL on which TAI is based. The performance of TT(BIPM2003) is used to assess the accuracy of TAI and to compare recent PFS measurements.

4.3 **Time links** (E.F. Arias, J. Azoubib, Z. Jiang, W. Lewandowski, G. Petit and P. Wolf; H. Konaté, M. Thomas and L. Tisserand)

The BIPM Time section organizes the international network of time links. In 2003, significant improvement was made on time transfer for TAI. The pilot experiment TAIP3, which began in summer 2002 to test the use of dual-frequency GPS P-code measurements for TAI links, continues. Several such time links have been introduced into TAI in 2003 and this process continues.

This allows the use of four techniques for clock comparison in TAI. At present, 36 % of the links are performed with the classical GPS common-view technique based on C/A-code measurements obtained from single-channel single-frequency receivers; about 33 % of the links are obtained from observations with multichannel receivers, some of them being GPS and GLONASS dual-code dual-system ones; 9 % are calculated from observations of dual frequency GPS receivers; and 15 % are links performed with the TWSTFT technique. As a result, there is an improvement in the accuracy for time transfer, and the whole system of time links becomes more reliable. In addition, the BIPM Time section continues to test other time and frequency comparison methods, such as those using phase measurements.

4.3.1 Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) code measurements

i) Current work

The BIPM publishes an evaluation of the daily time differences [*UTC – GPS time*] and [*UTC – GLONASS time*] in its monthly *Circular T,* and routinely issues GPS and GLONASS international common-view schedules. The international network of GPS common-view links used by the BIPM follows a pattern of local stars within a continent. All GPS links are corrected for satellite positions using IGS post-processed precise satellite ephemerides and those performed with single-frequency receivers are corrected for ionospheric delays using IGS maps.

ii) Standards for GPS and GLONASS receivers

The Time section continues its active involvement in the work of the CCTF Working Group on Global navigation satellite systems Time Transfer Standards (CGGTTS). This has involved the ongoing development of technical guidelines for manufacturers of receivers used for timing in Global navigation satellite systems. A staff member of the BIPM provides the secretariat of the CGGTTS.

iii) Multichannel GPS time links

Eighteen multichannel GPS links are used in the computation of TAI.

iv) IGS estimated ionospheric corrections

Ionospheric parameters estimated by the IGS are routinely used to correct all GPS links performed with single channel receivers for ionospheric delays in regular TAI calculations. A study of the possible correlation between ionospheric parameters and apparent variations in the hardware delays of dual-frequency receivers is under way.

4.3.2 Phase and code measurements from geodetic-type receivers

It will be recalled that GPS and GLONASS time and frequency transfer may also be carried out using dual-frequency carrier-phase measurements in addition to code measurements. This technique, already in common use in the geodetic community, can be adapted to the needs of time and frequency transfer. These studies are conducted in the framework of the newly created IGS working group on clock products, which replaces the IGS/BIPM Pilot Project for accurate time and frequency comparisons using GPS phase and code measurements.

Studies continue at the BIPM using two Ashtech Z12-T GPS receivers (one acquired in December 2003), one Javad Legacy GPS/GLONASS receiver and one Septentrio PolarX receiver acquired in May 2004.

The method developed to perform the absolute calibration of the Z12-T hardware delays allows us to use this receiver for differential calibrations of similar receivers world-wide. Calibration trips started in January 2001 and have continued ever since. As of June 2004, 26 such calibrations have taken place concerning 21 receivers. The new Z12-T serves as a local reference with which the traveling Z12-T is compared while at the BIPM.

Code P data from these receivers world-wide are collected for the pilot experiment TAIP3, using procedures and software developed in collaboration with the ORB. As of June 2004, 13 laboratories regularly provide such P3 data. Time links computed using these data are systematically compared to other available techniques, notably to two-way time transfer. We have shown that the long-term stability of these links is typically below 1 ns. We started using data from such receivers for the time links of TAI in July 2003.

The IGS now routinely publishes its clock products. Because several time laboratories participate both to TAI with P3 data and to the IGS network, it is

possible to compare results obtained through the IGS products and through TAIP3. Several multi-technique time link comparisons are under way.

One of the 3S Navigation receivers in operation at the BIPM is used to collect data for the International GLONASS Service Pilot Project (IGLOS-PP) sponsored by the IGS, in which the BIPM participates. The objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides.

4.3.3 Two-way time transfer

Two meetings related to TWSTFT activities have been held since October 2003. The BIPM collects two-way data from 12 operational stations and undertakes treatment of some two-way links. Nine TWSTFT links have been introduced into the computation of TAI; some others are in preparation for their introduction into TAI. The BIPM is also involved in the calibration of two-way time-transfer links by comparison with GPS. The Time section continues to elaborate BIPM TWSTFT reports, and a staff member of the BIPM provides the secretariat for the CCTF Working Group on TWSTFT.

4.3.4 Uncertainties of TAI time links

The evaluation of the Type A and Type B uncertainties of TAI time links has been concluded. Their values are published in *Circular T* since March 2004, together with the information on the time links used in each monthly calculation. Mainly because of lack of calibration, the Type B uncertainties of GPS links can reach 20 ns. This underlines the need to complete the calibration of all TAI time links.

4.3.5 Calibration of TAI time links

The BIPM is conducting a series of calibrations of GPS time equipment located in the time laboratories contributing to TAI. In 2003/2004, a total of 17 laboratories out of a possible 50 have been calibrated (AOS, APL, CH, CRL, IEN, KRISS, OCA, OP, NIST, NMIJ/AIST, NML, NPL, NTSC, PTB, TL, USNO and VSL). In addition, the Time section staff is developing methods for GPS/GLONASS time receiver calibrations. The BIPM is also taking part in the organization of TWSTFT calibration trips.

4.4 **Pulsars** (G. Petit)

Collaboration is maintained with radio-astronomy groups observing pulsars and analyzing pulsar data provided that it is of interest for us to study the potential capability of millisecond pulsars as a means of sensing the very long-term stability of atomic time. The Time section provides these groups with its post-processed realization of Terrestrial Time. The collaboration continues with the Observatoire Midi-Pyrénées (OMP), Toulouse, on a programme of survey observations.

4.5 **Space-time references** (E.F. Arias, G. Petit, J. Ray and P. Wolf)

Uniformity in the definition of space reference systems plays an increasingly important role in basic metrology, particularly for astro-geodetic techniques that contribute to the International Earth Rotation Service (IERS). Since 1 January 2001, a collaborative effort between the BIPM and the U.S. Naval Observatory (USNO) provides the Conventions Centre of the IERS. The new edition of the *IERS Conventions (2003)* has been finalized and published after receiving approval by the IERS Directing Board. This is a 127 page document summarizing the models, constants and procedures used for data analysis in the IERS, and for the astrometry-geodesy community at large.

A new web and ftp site for the *IERS Conventions* has been established at the BIPM (http://tai.bipm.org/iers/) and a user discussion forum has been set-up (http://tai.bipm.org/iers/forum/) for users to offer comments related to the future updates of the *IERS Conventions*.

Studies on improving the consistency of the *IERS Conventions* and on understanding the influence of inconsistencies on the IERS products started, in collaboration with other IERS analysis centers (IGN, OP).

Activities related to the realization of reference frames for astronomy and geodesy are being developed by E.F. Arias in co-operation with the IERS and with Argentine laboratories.

4.6 **Other studies** (P. Wolf)

The test of Lorentz invariance by comparing the frequencies of a hydrogen maser and a cryogenic sapphire microwave oscillator was continued throughout last year, in collaboration with the BNM-SYRTE (Paris Observatory) and the University of Western Australia (UWA). The measurements now cover a period of over 500 days and the most recent

results show an improvement by over a factor 2 with respect to the previously published results. A new theoretical analysis in the framework of the Standard Model Extension (SME) of particle physics has been carried out. In that framework, the experiment improves present limits by about one order of magnitude as shown in the most recent results. For further improvement, the experiments will have to be mounted on a rotating platform in the laboratory, which is expected to lead to improvements by another order of magnitude or more. Such an experiment is under way at UWA with the participation of P. Wolf during a two month stay at UWA. Other work in this field concerns the analysis of Doppler and clock-comparison experiments in the SME, like those planned for the ACES (Atomic Clock Ensemble in Space) experiment on board the international space station in 2008.

The ACES experiment includes a microwave link (MWL) for clock comparisons, which is expected to perform at least an order of magnitude better than present systems (GPS, TWSTFT) for frequency comparisons. Such a technique is essential for the comparison of present and future primary frequency standards. P. Wolf is involved in the modeling and data analysis of the MWL, and is co-supervising a Ph.D. student and a "DEA training" on that subject.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Altamimi Z., Boucher C., Ray J., Petit G., TRF Datum Definition and Geocenter Motion Estimate, *EOS Trans. AGU*, 2003, **84**(46), Fall Meeting Suppl., Abstract G21A-01.
2. Arias E.F., Bouquillon S., Representation of the International Celestial Reference System (ICRS) by different sets of selected radio sources, *Astron. Astrophys.*, 2004, **422**, 1105-1108.
3. Bize S., Wolf P. *et al*., Cold Atom Clocks, Precision Oscillators and Fundamental Tests, Springer, *Lecture Notes,* 2004, **648**, 189-207. arXiv:astro-ph/0310112.
4. De Biasi M.S., Osorio J., Amenna J., Esperón C., Arias E.F., The Observatorio Naval Buenos Aires time service, *Astrometry in Latin America*, AdeLA Publications Series N°1, 2004, 25-28.
5. Fey A.L., Ma C., Arias E.F., Charlot P., Feissel-Vernier M., Gontier A.-M., Jacobs Ch.S. Sovers O.J., Li J., MacMillan D., The second

extension of the International Celestial Reference Frame: ICRF-EXT.1, *Astron. J.,* 2004, **127**, 3587-3608.

6. Lamine B., Wolf P. *et al.*, Relic Gravitational Waves and the Isotropy of Spacetime, *Gravitational Waves and Experimental Gravity* (Dumarchez J. and Tran Thanh Van J. eds.), The Goi Publishers, Viet Nam, 2003, 307-314.
7. McCarthy D.D., Petit G. eds., IERS Conventions (2003), *IERS TN* 32*,* Verlag BKG, 2004, 127 pp.
8. Ray J., Petit G., Altamimi Z., Requirements for improved definitions and realizations of the ITRF origin and geocenter motion, AGU Fall meeting 2003, *EOS Trans. AGU*, 2003, **84**(46), Fall Meeting Suppl., Abstract G22B-09.
9. Soffel M., Klioner S., Petit G., Wolf P. *et al.*, The IAU 2000 Resolutions for Astrometry, Celestial Mechanics, and Metrology in the Relativistic Framework: Explanatory Supplement, *Astron. J.*, 2003, **126**, 2687–2706, arXiv:astro-ph/0303376.
10. Wolf P., Bize S., Clairon A., Luiten A.N., Santarelli G., Tobar M.E., Tests of Lorentz Invariance using a Microwave Resonator: an update, *Gravitational Waves and Experimental Gravity* (Dumarchez J. and Tran Thanh Van J. eds.), The Goi Publishers, Viet Nam, 2003, 315-321.
11. Wolf P., Bize S., Clairon A., Luiten A.N., Santarelli G., Tobar M.E., Tests of Lorentz Invariance using a Microwave Resonator: an update, *Proc. 2003 IEEE FCS and 17th EFTF* (Tampa, United States), 2003, 205-210.
12. Wolf P., Tobar M.E., Bize S., Clairon A., Luiten A.N., Santarelli G., Whispering Gallery Resonators and Tests of Lorentz Invariance, *Gen. Rel. Grav.*, 2004, **36**, 2351-2372.

4.7.2 BIPM publications

13. *Annual Report of the BIPM Time Section (2003)*, 2004, **16**, 89 pp.
14. *Circular T* (monthly), 7 pp.
15. Lewandowski W., Tisserand L., Determination of the differential time corrections for GPS time equipment located at the OP, NPL, IEN, PTB, and VSL, *Rapport BIPM*-2004/05, 2004, 17 pp.
16. Lewandowski W., Tisserand L., Determination of the differential time corrections for GPS time equipment located at the OP, PTB, AOS,

KRISS, CRL, NIST, USNO and APL, *Rapport BIPM*-2004/06, 2004, 29 pp.

17. Lewandowski W., Tisserand L., Determination of the differential time corrections for GPS time equipment located at the OP and CH, *Rapport BIPM*-2004/08, 2004, 15 pp.

4.7.3 Travel (conferences, lectures and presentations, visits)

E.F. Arias to:

- Sydney (Australia), 14–24 July 2003, for the 25th IAU General Assembly;
- Kashima (Japan), 16 September 2003, for a visit to the VLBI station, with a lecture on "Realization of the International Celestial Reference Frame by VLBI Observations";
- Tsukuba and Tokyo (Japan), 17 September 2003, for visits to the NMIJ/AIST and to the National Astronomical Observatory;
- Tokyo (Japan), 18 September 2003, for a visit to the NICT (formerly CRL), with a lecture on "BIPM activities on time and frequency"; 19 September 2003, for the Japan Review Committee of activities on space-time;
- Geneva (Switzerland), 6–8 October 2003, for the meeting of the Working Party 7A of the Study Group 7 of the ITU;
- Teddington (United Kingdom), 9–10 October 2003, for the 11th meeting of the CCTF Working Group on TWSTFT;
- Panamá (Rep. of Panamá), 27 October – 3 November 2003, for a visit to the CENAMEP, with a lecture on "Las escalas internacionales de tiempo. Actividad del BIPM";
- Vienna (Austria), 8–12 December 2003, for the UN/USA International Workshop on the Use and Applications of GNSS and for the 8th meeting of the Action Team on GNSS of COPUOS;
- Paris (France), 3 March 2004, for a conference at the Bureau des Longitudes on "Les échelles internationales de temps";
- Bern (Switzerland), 4–5 March 2004, for the IGS Workshop and Symposium;
- Vienna (Austria), 1 June 2004, for the 9th meeting of the Action Team on GNSS of COPUOS.

During the period April-June 2004, E.F. Arias has been interviewed by some ten radio stations from Argentina to discuss issues related to Argentinian legal time

Z. Jiang to San Diego (California), 1-5 December 2003, for the 35th PTTI meeting.

W. Lewandowski to:

- Warsaw (Poland), Space Research Centre, 20-27 August 2003, 17-24 September 2003, for a meeting on Space Geodesy dedicated to Jubilee of Prof. Barbara Kolaczek, 17-24 October 2003, 14-21 January 2004, 19-22 March 2004;
- Portland (Oregon, United States), 8-12 September 2003, for the 42nd meeting of the Civil GPS Service Interface Committee (chairmanship of the Timing Sub-committee), and for the 16th ION-GPS Technical Meeting;
- Brussels (Belgium), 7 October 2003, to attend a meeting of Galileo Joint Undertaking;
- Teddington (United Kingdom), 9-10 October 2003, for the 11th meeting of the CCTF Working Group on TWSTFT, oral presentation;
- San Diego (United States), 29 November – 6 December 2003, for the meeting of the participating stations of the CCTF Working Group on TWSTFT, for the Open forum on GPS and GLONASS standardization organized by the CCTF sub-group on GPS and GLONASS time transfer standards and for the 35th PTTI meeting with oral presentation;
- Guildford (United Kingdom), 5-7 April 2004, for the 18th EFTF, and co-authored lectures on "A simultaneous calibration of the IEN/PTB time link by GPS CV and TWSTFT portable equipment" by W. Lewandowski, F. Cordara, L. Lorini, V. Pettiti, A. Bauch, D. Piester and O. Koudelka, and "NIST-OP GPS receiver calibrations spanning twenty years: 1983-2003" by M. Weiss, V. Zhang, W. Lewandowski, P. Uhrich and D.Valat.

G. Petit to:

- Sydney (Australia), 16-25 July 2003, for the 25th General Assembly of the IAU, chair of the meeting of Commission 31 (Time);
- St Petersburg (Russian Fed.), 22-26 September 2003, for the "Journées 2003", lecture on "A new realization of Terrestrial Time"; Kalyazin (Russian Fed.), 29-30 September 2003, for a visit to the Radio-

observatory; Mendeleevo (Russian Fed.), 1 October 2003, for a visit to the VNIIFTRI time laboratory, lecture on "TAI and UTC";

- Nançay (France), 16 December 2003 and 22 January 2004, for participation in pulsar observations;
- Toulouse (France), 3-4 February 2004, for visits to the time department of CNES and to the Observatoire Midi-Pyrénées;
- Bern (Switzerland), 1-5 March 2004, for the IGS Workshop and Symposium and a visit to the METAS time laboratory;
- Guildford (United Kingdom), 5-7 April 2004, for the 18th EFTF meeting, and co-authored lectures on "Stability and accuracy of GPS P3 time links" by G. Petit and Z. Jiang, "Comparison of instrumental and empirical station timing biases for a set of Ashtech Z12T GPS receivers" by K. Senior, J. Ray and G. Petit;
- Paris and Limeil-Brévannes (France), 30 April and 3 May 2004, for a review group for the CNES.

P. Wolf to:

- Paris (France), 8–9 October 2003, invited to the GREX (Gravitation et Expériences), presentation on "Tests of Local Lorentz Invariance and Local Position Invariance: new theory, new results";
- São Paulo (Brazil), 10–15 October 2003, invited to the "Advanced International School on Time and Frequency Metrology", lectures on "Relativistic Tests using Time Metrology" and "Time Transfer";
- Perth (Australia), 17 April – 25 June 2004, for collaboration on experimental tests of Lorentz Invariance at the University of Western Australia;
- Melbourne (Australia), 28 April 2004, invited for a presentation at the University of Melbourne on "Testing Lorentz Invariance using Microwave Resonators";
- Sydney (Australia), 29 April 2004, invited for a presentation at the National Measurement Laboratory on "Testing Lorentz Invariance using Microwave Resonators" and visit of the NML-CSIRO Time section;
- Perth (Australia), 25 May 2004, invited for an Australian Institute of Physics seminar on "Testing Lorentz Invariance using Microwave Resonators".

4.8 Activities related to external organizations

E.F. Arias is a member of the IAU, participating in three of its working groups: on nutation, on the International Celestial Reference System, and on the redefinition of UTC. She is an associate member of the IERS, and a member of the International Celestial Reference System Product Centre and of the Conventions Product Centre of the IERS. She is a member of the International VLBI Service (IVS), and of its Analysis Working Group on the International Celestial Reference Frame. She is the BIPM representative at the Governing Board of the IGS. She is the BIPM representative to the Action Team on GNSS of COPUOS. She is a member of the Argentine Council of Research (CONICET) and an associate astronomer at the SYRTE, Paris Observatory. She is corresponding member of the Bureau des Longitudes.

J. Azoubib has been the BIPM representative to the Working Party 7A of the Study Group 7 of the ITU. Since his retirement, at the end of September 2003, E.F. Arias is the representative.

W. Lewandowski is the BIPM representative to the Civil GPS Service Interface Committee and chairman of its Timing Subcommittee. He is also a member of the Scientific Council of Space Research Centre of the Polish Academy of Sciences.

G. Petit is co-director of the Conventions Centre of the IERS and representative to the Directing Board of the IERS. He is a member of the IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology (RCMAM), of the IGS Working Group on Clock Products and of the Comité National Français de Géodésie et Géophysique.

P. Wolf is a member of RCMAM and of the GREX (Groupe de Recherche du CNRS: Gravitation et Expériences).

4.9 Activities related to the work of Consultative Committees

E.F. Arias is Executive Secretary of the CCTF.

J. Azoubib has been a member of the CCTF Working Group on Two-way Satellite Time and Frequency Transfer (TWSTFT) and a member of the CCTF Working Group on TAI.

W. Lewandowski is secretary of the CCTF Working Group on TWSTFT and secretary of the CCTF Working Group on Global Navigation Satellite Systems Time-transfer Standards.

G. Petit is a member of the CCTF Working Groups on TAI, on Algorithms and on the CGGTTS.

4.10 Visitors to the Time section

- Dr D.D. McCarthy (USNO), 23 October 2003.
- Dr K. Senior (USNRL), 12 November 2003.
- Dr P. Tavella and Dr G. Panfilo (IEN), 17 February 2004.
- Ing. C. Donado (CENAMEP), 29 March – 1 April 2004.
- Dr J. Nawrocki (SRC), 28 May – 28 June 2004.

4.11 Guest worker

- Dr J. Ray (US National Geodetic Survey), 1 September 2003 – 31 August 2004.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect
(D. Reymann and S. Solve; R. Chayramy)

5.1.1 Josephson array measurements

This year, we continued our work on SINIS programmable arrays (see report 2002-2003). In December 2003, the PTB gave us a second programmable array: a 1.2 V array consisting of 8192 junctions divided into 14 segments containing from 1 to 4096 junctions each. Compared to the first array given to the BIPM by the PTB, this array can be considered as "perfect" in the sense that all segments contain a exact binary arrangement of 1, 1, 2 , 4 … up to 4096 junctions. We measured the voltage difference between the largest segment and that of the series connection of all the other segments, and found that, to within a standard uncertainty of 0.1 nV, there was no voltage

difference between the two sections in this configuration. With all segments of the SINIS array connected in series, the total voltage was compared to an equal voltage generated across an unbiased SIS array. Again, to within an uncertainty of 0.1 nV, no voltage difference was observed between the two different types of array.

In a separate activity, at the request of the SIRIM (Malaysia) we investigated the functioning of two arrays operating at 1 V and at 10 V, respectively.

5.1.2 EUROMET Project 723: 1.09 V comparison supplementing BIPM.EM-K10.a

In March 2004 the BIPM participated in EUROMET Project 723, a comparison of Josephson standards at 1.09 V. The traveling standard was the portable Josephson voltage standard built by the VNIIM and based on a SINIS array (see Katkov A. *et al*., *Metrologia*, 2003, **40**, 89-92). The BIPM used the SIS array system already described in the previous Josephson comparison publications. The first series of measurements showed a difference of about 2 nV between the two instruments. The origin of this voltage difference was traced to the effect of electromagnetic interference on the portable standard. This problem was eliminated by connecting the common connection point of the two arrays to ground and by biasing the SINIS array close to the centre of the steps. Doing this, we obtained the result:

$$U_{\mathrm{SINIS}} - U_{\mathrm{SIS}} = +0.07 \text{ nV}; \qquad u_{\mathrm{C}} = 0.13 \text{ nV}$$

where u_{C} is the overall uncertainty ($k = 1$).

5.1.3 Zener diode measurements

We continue using the automatic system, which was commissioned last year, for the calibration of electronic voltage standards referenced to Zener diodes. From time to time, we measure Zeners directly with the Josephson system in order to check the validity of the results obtained with the automatic system.

5.2 Electrical resistance and impedance

5.2.1 Dc resistance (F. Delahaye and R. Goebel; A. Jaouen)

The BIPM participated in EUROMET.EM-K10, a EUROMET key comparison of 100 Ω dc resistance standards piloted by the PTB. The four 100 Ω traveling standards were measured five times at the BIPM in December 2003. The standards were compared directly with the quantized resistances corresponding to the $i = 2$ plateaus of two quantum Hall effect (QHE) devices using the BIPM cryogenic current comparator. The four standards were found to be stable to within 2 parts in 10^8 during their stay at the BIPM.

We further investigated the technique of placing multi-terminal QHE devices in series or parallel by means of connections between devices made at the top of the cryostat where they are readily accessible without removing the device. The technique was used to check the 4/1 ratio of the 400 Ω /100 Ω Hamon resistive divider which is part of our chain linking capacitance standards to resistance standards. Two QHE devices operated on the $i = 2$ plateaux were placed either in series or in parallel using triple links at the top of the cryostat. Thus, two quantized Hall resistance with ratio 4/1 (25 812 Ω and 6453 Ω) are available. They were compared respectively with the 400 Ω and 100 Ω resistances of the Hamon device using a current comparator bridge with appropriate ratio (6453/100) operated at 1 Hz. Each set of wires at a given potential and connecting the QHE devices in series or in parallel was guarded and appropriate guard voltages were applied. We found that the 4/1 ratios as defined by the QHE devices and the Hamon divider agree to within 1 part in 10^8.

5.2.2 Maintenance of a reference of capacitance and capacitance calibrations (F. Delahaye and R. Goebel; R. Chayramy)

Until now, our capacitance measurements have covered the frequency range from 1000 Hz to 1592 Hz. This year we extended the frequency range of the BIPM capacitance measurements over the range 500 Hz to 6000 Hz, allowing the evaluation of the frequency dependence of capacitance standards. In particular, the procedure could be applied to check the frequency dependence of a calculable standard of capacitance. To cover this extended frequency range, our quadrature bridge was adapted to operate at five frequencies: $f_0 = 1541$ Hz, $f_0/3 = 513$ Hz, $f_0/1.5 = 1027$ Hz, $2 f_0 = 3082$ Hz, and $4 f_0 = 6164$ Hz. To do this, we always use in the bridge

the same pair of resistors (R = 51.6 kΩ) of known frequency dependence, but we change either the pair of capacitors (C = 1000 pF, 2000 pF or 3000 pF) or the ratio of the main inductive voltage divider in the bridge.

In the special case where the main divider ratio is 1/1, the balance equation of a quadrature bridge is $2\pi RCf = 1$. A more general form of this equation is obtained if the main divider ratio, k, takes on other values. In our case, a divider ratio of 1/1 results in balance frequencies equal to $2f_0$, f_0 or $f_0/1.5$ when C is equal to 1000 pF, 2000 pF or 3000 pF, respectively. To operate at the two extreme frequencies, $f_0/3$ or $4f_0$, the main divider with ratio 1/1 is replaced by one with ratio 1/4 or 4/1. The balance frequency is $f_0/3$ if the pair of 3000 pF capacitors is used together with a ratio 1/4, or $4f_0$ if the pair of 1000 pF capacitors and a ratio 4/1 is used.

Based on the measurements carried out with our multi-frequency quadrature bridge, we evaluated the frequency dependence of 10 pF and 100 pF fused silica capacitors. A slight decrease of the capacitances is observed in the frequency range of interest.

5.3 Characterization of electronic voltage standards (T.J. Witt)

We continued our analysis of complete dc voltage measurement cycles that include polarity reversals in order to gain a better understanding of limitations imposed by intrinsic noise processes in routine measurement procedures. In the collaborative project with the NIST to apply the techniques used at the BIPM to measure and characterize noise and stability of electrical measurement instruments, we have characterized the noise of 25 electronic voltage standards and verified that a useful working model to describe the noise is a simple power law of the spectral density containing two terms: white noise and 1/f noise. We have begun work on using a very low frequency method using sinusoidal temperature variations to determine the temperature coefficients of Zeners.

5.3.1 Characterization of the noise and stability of voltage measurement procedures that include polarity reversals (T.J. Witt)

Polarity reversal is a standard technique used in electrical metrology to remove the effects of thermal electromotive forces (EMFs). To investigate how it affects the noise and stability of electrical measuring instruments, we used both an analogue and a digital nanovoltmeter and an automated

polarity-reversal switch to measure voltages in the detectors themselves as well as in Zener-diode electronic voltage standards and in standard cells. Data were mostly analyzed using three time-series analysis methods; the spectral density, the Allan variance and wavelets. All of the measurements were repeated using the unipolar method (no polarity reversals) and the results were compared. One purpose of this exercise was to demonstrate that, contrary to a commonly held belief, polarity reversals do not affect $1/f$ noise. We showed that the Allan variances and spectral densities calculated from data acquired using the two procedures are closely compatible, particularly for the times (or frequencies) corresponding to the $1/f$ noise regime. In our past work, using only the unipolar method, we had already developed a power-law model for the spectral densities of Zeners that includes two types of noise, white and $1/f$. This model is confirmed by the results of polarity-reversed measurements. For Zener measurements, at frequencies for which the direct voltage (that of the Zeners) is dominated by $1/f$ noise, the unreversed voltage is dominated by white noise. The spectrum and Allan variance of the unreversed voltage readings serve to monitor the noise characteristics of the voltmeter during Zener measurements. Since the regular square waveform produced by polarity reversals can be Fourier synthesized from sine waves, our results can be considered as a demonstration that ac measurement techniques do not remove the effects of $1/f$ noise. In our analysis of time series, spectral densities are calculated from Fourier transforms of the measured voltages, while Allan variances are calculated from algebraic expressions. We validated our measurement and analytical procedures by comparing the spectral density for the noise voltage of an 80 Ω resistor at room temperature with that predicted by the Nyquist expression, $4kTR$ (k is the Boltzmann constant, R the total noise resistance and T the absolute temperature) and found agreement to within 5 %. The calculated Allan variance is also in good agreement with the Nyquist expression. Details of the polarity reversal and noise thermometry work were presented at CPEM 2004, London (United Kingdom).

5.3.2 Joint project with the NIST to characterize the noise and stability of dc voltage standards and measurement instruments (T.J. Witt)

Our collaboration with Dr Y. Tang of the Electricity Division of the NIST has continued. This joint project aims to characterize the noise of dc voltage standards and voltmeters at the NIST. Preliminary results were presented at the NCSL International conference and workshop in August 2003. We have

now determined the noise properties of 25 Zener voltage standards. Although the measurements at the NIST were made with automated Josephson standards using digital voltmeters, the results agree well with those obtained for 13 Zeners at the BIPM using a manual Josephson system and an analog voltmeter. We have good confirmation of the trends that associate lower noise levels with certain model Zeners. In another part of this work, we used digital voltmeters to directly measure output voltages between 0 mV and 2 mV on the 1 mV or 10 mV ranges. As expected, the noise is white, but we find two surprising results. First, when switching the voltmeter from the 1 mV range to the 10 mV range, the Allan deviation increases by a factor of 1.8, not 10. Second, recalling that digitizing any analogue signal results in an inherent "quantization error" causing values to be quantized in steps of Δ, the resulting standard uncertainty, assuming a uniform probability distribution function, is $\Delta \cdot 12^{-1/2}$. The surprise is that we have obtained Allan deviations up to three times smaller than this. Detailed results of the NIST collaboration were presented at CPEM 2004, London (United Kingdom).

5.4 A novel scheme for measuring temperature coefficients of electronic voltage standards (T.J. Witt)

Part of the unique characterization of electronic voltage standards sent to the BIPM for calibration or used by the BIPM in ongoing BIPM key comparisons is the determination of the residual temperature coefficients of the two output voltages. These determinations require several days to carry out and the uncertainties are high because of temporal drift and the presence of inherent $1/f$ noise. We have had some success in reducing the time constant corresponding to the response of the Zener under test to a programmed "step" change in temperature in the thermostated enclosure in which the measurements are made. This led us to attempt to apply sinusoidal temperature variations and to use a variant of phase sensitive detection to determine the temperature coefficient of voltage. In terms of spectral density, the $1/f$ corner frequency for Zener measurements is normally in the range 0.1 Hz to 0.01 Hz whereas, because of the slow response of the chassis of the Zener to temperature changes, to obtain useful results the reference frequency of the temperature oscillations cannot be set above 1/(30 min) = 0.6 mHz. With phase sensitive detection the capability of extracting a signal from noise is limited if the reference frequency is below the corner frequency. However, modern signal processing software is capable of fast Fourier analysis of the output signal (Zener voltage) and

detecting even small peaks at the reference frequency. This is the basis of our analytical method. First results are promising and we hope to pursue further development.

5.5 **Thermometry** (R. Goebel, S. Solve, M. Stock and Y. Yamada*)

In thermometry, a total of about 50 working thermometers were calibrated between 0 °C and 30 °C for the other sections of the BIPM.

The BIPM is the pilot laboratory for key comparison CCT-K7, a comparison of water triple point cells. Most of the measurements were completed by July 2003. During the initial measurements an abnormal drift was observed for one participant's cell. They were asked to provide a second cell which was measured subsequently. All measurements were completed in nine months and involved a total of 64 ice mantles. We are now preparing the comparison report which we plan to distribute in mid-2004. The results obtained in this new comparison are of much higher quality than those of the 1995 comparison because of the much better day-to-day reproducibility of our measurements. This is a consequence of the modernization of the instrumentation, and especially through improved temperature control of the standard resistor and the use of an automatic resistance bridge.

As a consequence of the closure of the Radiometry and Photometry section, the collaboration with the NMIJ/AIST (Japan) on the thermodynamic temperature determination of high-temperature eutectic fixed points had to be finished after one year of Y. Yamada's work at the BIPM. In spite of the short time available for this project we could show the feasibility of all steps starting from the preparation of the crucibles with the eutectic alloy to the thermodynamic temperature determination. The latter was accomplished by measuring the spectral radiance with two filter radiometers which were calibrated against our cryogenic radiometer. One offshoot of the project was the development of a new type of eutectic crucible that is not only more robust but also cheaper than conventional cells. Another ramification was the development of a new technique for the characterization of imperfect imaging (the so-called size-of-source effect) of the filter radiometers by which some of the difficulties experienced with the traditional techniques were overcome. The results of this project were presented at the TempMeko conference in June 2004.

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* NMIJ/AIST (Japan).

5.6 BIPM ongoing key comparisons in electricity
(F. Delahaye, D. Reymann and T.J. Witt; A. Jaouen)

Since June 2003, in the framework of the programme of ongoing BIPM key comparisons of electrical standards, the following comparisons were carried out.

In the field of voltage standards using Zener traveling standards, we have completed comparisons at 10 V with the CSIR-NML (South Africa) and with the NML (Ireland), and a comparison at both 1.018 V and 10 V with the NML-CSIRO (Australia). The results have been accepted by the CCEM for inclusion in the BIPM.EM-K11.a and BIPM.EM-K11.b comparisons of the KCDB. In the case of the CSIR-NML and the NML, at the same time as the two formal comparisons at 10 V, informal comparisons at 1.018 V were also carried out.

In the field of dc resistance standards, we have completed comparisons at 10 kΩ with the EIM (Greece) and at 1 Ω with the KRISS (Rep. of Korea). The results have been accepted by the CCEM for inclusion in the BIPM.EM-K13.a and BIPM.EM-K13 comparisons of the KCDB.

5.7 Calibrations (F. Delahaye, D. Reymann and T.J. Witt; R. Chayramy and A. Jaouen)

This year the Electricity section calibrated the following standards: Zener diode standards at 1.018 V and 10 V for Belgium, Bulgaria, Czech Republic, Egypt, Malaysia, Romania and Serbia and Montenegro; 1 Ω resistors for Brazil, and Serbia and Montenegro; 100 Ω resistors for Belgium; 10 kΩ resistors for Belgium, Brazil, the Czech Republic, Denmark, Serbia and Montenegro; 10 pF capacitors for Belgium, Canada, Finland, Israel; and 100 pF capacitors for Belgium, Canada, Finland, France and Israel.

5.8 Publications, lectures, travel: Electricity section

5.8.1 External publications

1. Solve S., Stock M., An international comparison of water triple point cells, *Proc. 11th Int. Metrology Congress*, Toulon, 2003, 5 pp.
2. Goebel R., Stock M., Final report on the subsequent bilateral comparison of cryogenic radiometers CCPR-S3 between the BIPM and the IEN, *Metrologia*, 2003, **40**, *Tech. Suppl*., 02001.

3. Köhler R., Stock M., Garreau C., Final Report on the international comparison of luminous responsivity CCPR-K3.b, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 02001.

5.8.2 BIPM reports

4. Delahaye F., Holiastou M., Flouda E., Jaouen A., Witt T.J., Bilateral comparison of 10 kΩ standards (ongoing BIPM key comparison BIPM.EM-K13.b) between the EIM, Greece and the BIPM, September 2003, *Rapport BIPM*-2004/07, 2004, 8 pp.

5. Reymann D., Frenkel R., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the NML-CSIRO (Australia) and the BIPM, October to December 2003 (part of the ongoing BIPM key comparisons BIPM.EM-K11.a & b), *Rapport BIPM*-2004/03, 2004, 8 pp.

6. Reymann D., Power O., Witt T.J., Bilateral comparison of 10 V standards between the NML (Ireland) and the BIPM, March to May 2004 (part of the ongoing BIPM key comparison BIPM.EM-K11.b), *Rapport BIPM*-2004/09, 2004, 12 pp.

7. Reymann D., Tarnow E., Witt T.J., Bilateral comparison of 10 V standards between the CSIR-NML (South Africa) and the BIPM, October to December 2003 (part of the ongoing BIPM key comparison BIPM.EM-K11.b), *Rapport BIPM*-2004/02, 2004, 13 pp.

8. Yu K.M., Jaouen A., Delahaye F., Witt T.J., Bilateral comparison of 1 Ω standards (ongoing BIPM key comparison BIPM.EM-K13.a) between the KRISS, Republic of Korea and the BIPM, June 2003, *Rapport BIPM*-2004/01, 2004, 7 pp.

5.8.3 Travel (conferences, lectures and presentations, visits)

R. Goebel to the MSL, Lower Hutt (New Zealand), 25-26 November 2003, to participate in a technical audit.

S. Solve to Dubrovnik (Croatia), 22-25 June 2004, to participate at the TempMeko conference.

M. Stock to:

- Ljubljana (Slovenia), 29-31 March 2004, for the EUROMET meeting of contact persons for thermometry;

- IEN, Turin (Italy), 22-23 April 2004, for the EUROMET meeting of contact persons for radiometry and photometry;
- NIST, Gaithersburg (United States), 10-14 May 2004, for CCPR working group meetings;
- Dubrovnik (Croatia), 22-25 June 2004, to give a talk at the TempMeko conference entitled "Thermodynamic temperature measurements of metal-carbon eutectic fixed points" and for CCT working group meetings.

T.J. Witt to:

- the 16th meeting of EUROMET contact persons in electricity and magnetism held at the BEV, Vienna (Austria), 25-26 November 2003; he gave a report on the Working Group on Low-frequency Quantities (WGLF) and the Working Group on Radiofrequency Quantities (GT-RF) meetings of 4-5 November 2003;
- the 6th meeting of the APMP Technical Committee on Electricity and Magnetism, 1-2 December 2003, in Singapore; on 1 December he gave a report on the WGLF and GT-RF meetings of 4 and 5 November 2003 and delivered a lecture entitled "Overview of the activities of the BIPM Electricity section"; on 2 December he delivered a three hour workshop lecture, with demonstrations, entitled "Introduction to and Practical Applications of Spectrum Analysis in DC Electrical Metrology: Voltmeters and Zener Voltage Standards".

T.J. Witt, M. Stock, F. Delahaye, D. Reymann, R. Goebel and S. Solve to the CPEM 2004, London (United Kingdom), 28 June to 2 July 2004:

- F. Delahaye and R. Goebel presented a poster entitled "Evaluation of the frequency dependence of the resistance and capacitance standards in the BIPM quadrature bridge", *CPEM 2004 Digest*, pp. 372-373;
- T.J. Witt and Y. Tang (NIST) presented a poster entitled "Investigations of Noise in Measurements of Electronic Voltage Standards", *CPEM 2004 Digest*, pp. 172-173;
- D. Reymann presented a lecture entitled "Sources of errors in measurements of 1.018 V Zener voltage references and suggestions for treating them", *CPEM 2004 Digest*, pp. 68-69;
- T.J. Witt presented a lecture entitled "Allan Variances for DC Voltage Measurements with Polarity Reversals", *CPEM 2004 Digest*, pp. 64-65;
- T.J. Witt organized and presided an informal meeting on quantum electrical metrology on 1 July following the CPEM sessions;

- T.J. Witt co-authored the lecture presentation by Yi-hua Tang (NIST) entitled "1/*f* Noise Floor of Solid-State Voltage Standards" at the NCSL International Workshop and Symposium, 18 August 2003, Tampa, Florida. The text is available in the NCSL International 2003 Conference Proceedings, Catalog Number: PR-2003.

5.9 Activities related to external organizations

T.J. Witt is a member of the Executive Committee of the CPEM.

T.J. Witt, F. Delahaye and D. Reymann are members of the Technical Committee for CPEM 2004.

F. Delahaye is the BIPM contact person of Working Group 2 of the Joint Committee for Guides in Metrology, JCGM (Revision of the VIM).

5.10 Activities related to the work of Consultative Committees

T.J. Witt is Executive Secretary of the CCEM, member of the WGLF and takes part in meetings of the GT-RF. He attended the meeting of the RMO technical chairpersons in electricity and magnetism.

M. Stock is Executive Secretary of the CCT and the CCPR, and a member of the CCT and CCPR working groups on key comparison, of the CCT working group on uncertainties and of the CCPR CMC Working Group.

5.11 Visitors to the Electricity section

- Prof. K. Ikeda, Tokushima University, Tokushima (Japan), 2 September 2003, for visits of the high temperature laboratory.
- Dr S. Sivinee and Ms C. Ajchara (NIMT), 3-5 March 2004.
- Dr H.C. Apfeldorfer, Head Physical Standards Division (INPL), 11 March 2004.
- Mr S. Kajane (Botswana Bureau of Standards), 22 March 2004.
- Dr A. Katkov (VNIIM), 22-23 March 2004.
- Messrs. H. Moody, K. Jaeger, and J.-C. Krymick (SCLSI), 23 March 2004.
- Mrs G. Dankos and Ms T. O. Varga (OMH), 11 June 2004.

5.12 Guest worker

- Dr Y. Yamada (NMIJ/AIST), 1-30 September 2003 and 1-12 December 2003.

6 IONIZING RADIATION (P.J. ALLISY-ROBERTS)

6.1 X-and γ-rays
(P.J. Allisy-Roberts, D.T. Burns, C. Kessler* and S. Picard**; P. Roger)

6.1.1 Dosimetry standards and equipment

Replacement high-voltage dividers, having been designed last year, were constructed. One was installed for the medium-energy x-ray facility in September 2003 and the other for the low-energy facility in January 2004. The latter was tested extensively by comparison with the existing divider to allow a more robust estimate of the calibration uncertainty. New measurements of air-attenuation coefficients for both facilities showed no significant changes. A Compton spectrometer using a hyper-pure germanium detector has been assembled and calibrated for energy. Preliminary spectral measurements have been made in low-energy x-rays. A new, high-isolation dc voltage supply was designed and constructed for the anode current measurement in medium-energy x-rays.

The medium-energy x-ray tube, which has served since 1974, was replaced in May 2004 following the re-measurement of half-value layers and reference chamber calibration coefficients using the old tube. Work is underway to re-establish the CCRI reference qualities. Higher air kerma rates will be implemented, requiring a re-evaluation of ion recombination corrections for the primary standard.

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* A new member of staff since 23 April 2004, previously a Research Fellow.

** Transferred to the Ionizing Radiation section from 22 April 2003. For publications related to the Length section, see Section 2.8.1.

Horizontal and vertical beam profile measurements were repeated on the new 250 TBq ^{60}Co source to establish the mechanical stability of the facility. The positions of the beam centre and edges were reproduced to around 0.2 mm. The profiles for the 170 TBq ^{60}Co source were also measured. The results were used to derive non-uniformity correction factors for the primary standard in each beam. An analytic model was developed to derive improved non-uniformity correction factors for spherical chambers. A new water phantom was constructed for the 250 TBq ^{60}Co source. The ion recombination correction for the BIPM primary standard has been verified in the 250 TBq beam. Two new graphite cavity chamber standards are under construction and should be tested before the end of the year.

Quality assurance calibrations have continued in all of the reference x- and γ-ray beams, as well as at the new mammographic radiation qualities.

Work has begun on a graphite calorimeter standard for absorbed dose measurements. Several low-noise thermistor bridges, a power supply and measuring equipment have been assembled and tested, and a system for precise temperature calibration developed. The current stage consists of an accurate measurement of specific heat capacity for an ensemble of graphite samples that are representative of the calorimeter core. Work is in progress on determining the electrical energy input and on minimizing the corrections for heat losses and sample impurities.

6.1.2 Dosimetry comparisons

Air kerma and absorbed dose to water comparisons in ^{60}Co γ-rays were carried out in November 2003 with the BNM-LNHB (France). Reports of previous air kerma comparisons with the LNMRI (Brazil), NMIJ/AIST (Japan), NPL (United Kingdom) and the PTB (Germany) have been delayed as changes are being made to the various standards. The report for the ENEA (Italy) has been published. The summary report for all previous absorbed dose to water comparisons will be circulated to the CCRI for final approval prior to publication in the KCDB once the NPL result is approved. The reports of the OMH (Hungary) and the VNIIFTRI (Russian Fed.) for this quantity have been published.

Following the agreement of the CCRI(I) in May 2003 on new values for correction factors for the low- and medium-energy x-ray standards, based on Monte Carlo calculations, the new values were published in *Metrologia* and adopted with effect from 1 October 2003. Degrees of equivalence for key

comparison results based on these values were evaluated, verified by each participating NMI and published in the KCDB by the end of November 2003.

The calculations needed to evaluate correction factors for the γ-ray standards are in progress. Calculations of x-ray spectra have also commenced with the modeling of the x-ray tube and collimation.

Reports of previous x-ray comparisons with the ARPANSA (Australia), BEV (Austria), NIM (China), NIST (United States) and the NMi (Netherlands) are in preparation. These comparison reports evaluate degrees of equivalence and the results will be included in the KCDB once they have been approved by the CCRI.

The four transfer chambers for the high-energy absorbed-dose CCRI key comparison continue to be measured periodically in the BIPM ^{60}Co beam.

6.1.3 Calibration of national standards for dosimetry

Procedures and technical instructions in accordance with the BIPM Quality manual for the dosimetry calibration services were completed and an external audit of the services carried out in December 2003. No non-compliances were recorded.

A total of nine series of calibrations of national standards were made in low- and medium-energy x-rays for the BNM-LNHB (France), CIEMAT (Spain), IAEA, NRPA (Norway) and the STUK (Finland).

Twenty-three calibrations of national standards were carried out in the BIPM γ-ray beams in terms variously of air kerma, absorbed dose to water and ambient dose equivalent, as requested by the CIEMAT (Spain), IAEA, HIRCL (Greece), the KRISS for the KFDA (Rep. of Korea), NRPA (Norway) and the STUK (Finland).

The IAEA/WHO dosimetry assurance programme continued to be supported with reference irradiations in the ^{60}Co beam.

6.2 **Radionuclides** (C. Michotte and G. Ratel; C. Colas*, S. Courte**, M. Nonis and C. Veyradier***)

6.2.1 International key comparisons of activity measurements

The CCRI(II) has embarked on an extensive programme of international activity comparisons, for most of which the BIPM is the pilot laboratory, to enable NMIs to support their measurement claims. Of the nineteen such comparisons that have been completed in the past, the results of eight are already published in the KCDB, a further five more recent comparisons are at the Draft B report stage and the remaining six are at the Draft A report stage.

The BIPM measurement chain for the coincidence method has been redesigned and replaced. The new system, controlled by the atomic clock frequency from the BIPM Time section, includes a more sophisticated dead-time module that has a constant offset of only 4 (1) ns over the whole dead-time range from 2 μs to 51 μs, which is an improvement over the original system.

The radiochemical laboratory is in the process of being updated to accommodate the additional workload of the comparison programme.

i) Comparison of activity measurements of a ^{192}Ir solution

The amendments proposed by the participants to the Draft A report of this comparison have been incorporated and a more detailed report including uncertainty budgets is being prepared. The link to the BIPM comparison for ^{192}Ir has been made and a linking report is in circulation.

ii) Comparison of activity measurements of a ^{241}Am solution

The activity of the BIPM sample has been measured using the coincidence method with a proportional counter working at atmospheric pressure. No extrapolation was carried out because the counter was set on the alpha plateau and was thus insensitive to electrons as well as to x- and γ-ray scattering in the counter. This insensitivity was confirmed using a ^{60}Co source. The activity concentration obtained with a relative standard uncertainty of 1.7×10^{-3} is in good agreement with the other participants.

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* Retired on 31 December 2003.
** Employed since 12 November 2003.
*** Shared with Publications section; retired on 30 September 2003.

This comparison is now complete after some postponements, particularly due to dispatch problems of the solution to a number of the twenty-two participants. The BIPM advised two laboratories of discrepant values, in accordance with the guidelines. Each laboratory has checked their results and resubmitted values with explanations for the changes. These revised results are being incorporated into the Draft A report with a note to identify the practice that has been followed.

iii) Comparison of activity measurements of a ^{54}Mn solution

The solution of ^{54}Mn prepared and dispatched by the PTB to 23 laboratories has been measured by 19 laboratories, 18 of them using primary measurement methods. Ten different methods have been used producing 25 independent results. No impurity has been detected in the solution. Apart from one result, all the others are contained in a band covering the range +1.35 % to -1.2 % from the mean value. The results obtained with the CIEMAT/NIST method based on liquid-scintillation used by three laboratories (the BIPM, IRMM and the PTB) exhibit an unusual spread that should be investigated. The Draft A report is in preparation to be sent to the participants during the summer.

iv) Comparison of activity measurements of a ^{125}I solution

A comparison of activity measurement of a solution of ^{125}I has just started. The solution has been prepared and dispatched to the participants by the NPL. The BIPM received four extra ampoules with about six times more activity to be measured directly in the SIR ionization chambers. This should allow the outcome of the comparison to be entered in the SIR database. The BIPM is standardizing the solution by means of the liquid-scintillation method. Results are due to be sent to the BIPM by the end of August 2004.

v) Comparison of activity measurements of a ^{90}Y solution

The BIPM participated in this comparison organized on behalf of the CCRI(II) by the IAEA. The solution of ^{90}Y was prepared by the NIST. The BIPM measured the solution with a liquid-scintillation spectrometer using the CIEMAT/NIST method. The result obtained by the BIPM is in good agreement with the seven other results and with the mean value of the comparison at one standard deviation. The Draft B report is in circulation.

vi) Comparison of activity measurements of a ^{32}P solution

Following the recommendations of the CCRI(II), a further comparison of a ^{32}P solution between the three laboratories that obtained discrepant results in the 2003 comparison is being organized this summer. Another three previous participants will be included to ensure that the new results can be linked to the others and the opportunity is being made to enable some new participants to join this key comparison.

6.2.2 Other key comparisons

The comparison of activity measurements of a solution of ^{65}Zn is in progress. The Draft A report should be issued this summer.

6.2.3 International reference system (SIR) for gamma-ray emitting radionuclides

During 2003 the BIPM received 15 ampoules, each containing one of eight radionuclides, from six laboratories: the BNM-LNHB (six ampoules filled with three different radionuclides), CIEMAT, CNEA, IRA, NPL (five ampoules filled with three different radionuclides) and the RC. As a consequence, nine new results have been registered for the radionuclides of ^{18}F, ^{60}Co (two results), ^{67}Ga, ^{90}Y, ^{103}Ru, ^{153}Sm, ^{201}Tl and ^{222}Rn.

In addition, ampoules prepared for different key comparisons have been measured in the SIR ionization chambers: one ampoule of ^{54}Mn prepared by the PTB and one ampoule of ^{90}Y prepared by the NIST. This will allow a direct link of the individual results of each of these comparisons to the KCDB. The measurement of one ^{18}F ampoule prepared and sent by the NPL will also serve to link an international comparison to the KCDB. Finally, four ampoules of ^{85}Kr filled with different gas pressures by the BNM-LNHB were measured in the SIR to study the influence of gas pressure on the ionization chamber response. The need for this study was identified during the analysis and publication of the results of the BIPM.RI(II)-K1.Kr-85 comparison.

Thirty-one ongoing BIPM comparison reports have been published in the KCDB during the last twelve months, including links for CCRI(II) or RMO comparisons in eight cases. A further five Draft B reports are in circulation and three others are in preparation.

The SIR measurement system is in the process of being updated with the development of new electronics (a Keithley electrometer integrated with a Townsend balance system) and an improved hardware/software interface.

The project, in collaboration with the NPL on the determination of a mathematical solution to the SIR efficiency curve as a function of the γ-ray energy is progressing well. The objective is to produce software to calculate the efficiency curves for both beta particles and photons by solving the model equations by the non-linear least-squares technique. As a first step, a photon efficiency curve has been produced, using the SIR KCRV's as input data. The second step is concentrating on including the correction for impurities in each individual SIR measurement in the model, followed by a detailed treatment of uncertainties and correlations. Finally, an improved model for the beta efficiency curve and beta spectrum shapes will be defined. The project should be completed by the autumn 2004.

6.2.4 Gamma spectrometry

Impurity checks have been made for ^{18}F, ^{51}Cr, ^{85}Sr, ^{103}Ru and ^{131}I submitted to the SIR. No impurity was identified in any of these ampoules nor in those submitted for the ^{125}I activity comparison of the CCRI(II). The ^{153}Sm ampoule from the BNM-LNHB was also measured and this identified a numerical error that occurred in the impurity analysis at that laboratory. The corrected impurity contents are in agreement with the values measured at the BIPM within one standard uncertainty.

6.3 Publications, lectures, travel: Ionizing Radiation section

6.3.1 External publications

1. Allisy-Roberts P.J., Burns D.T., Mutual recognition arrangement and primary standard dosimetry comparisons, *Standards and Codes of Practice in Medical Radiation Dosimetry: Proceedings of an International Symposium, Vienna, 25-28 November 2002*, IAEA, 2003, **1**, 11-19.
2. Burns D.T., Calculation of wall and non-uniformity correction factors for the Bureau International des Poids et Mesures air kerma standard for ^{60}Co using the Monte Carlo code PENELOPE, 2003, *Standards and Codes of Practice in Medical Radiation Dosimetry: Proceedings of an*

International Symposium, Vienna, 25-28 November 2002, IAEA, 2003, **1**, 141-149.

3. Burns D.T., Changes to the BIPM primary air kerma standards for x-rays, *Metrologia*, 2004, **41**, L3.
4. Burns D.T., Degrees of equivalence for the key comparison BIPM.RI(I)-K3 between national primary standards for medium-energy x-rays, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06036.
5. Burns D.T., Degrees of equivalence for the key comparison BIPM.RI(I)-K2 between national primary standards for low-energy x-rays, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06031.
6. Michotte C., Nonis M., Développement d'une porte linéaire conservant les qualités spectroscopiques d'un spectromètre GeHP (Journées de spectrométrie gamma et X, Saclay, octobre 2002), *Bul. BNM.*, 2003, No. 123, 19-22.
7. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Gd-153 of activity measurements of the radionuclide ^{153}Gd, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06003.
8. Ratel G., Michotte C., Hino Y., BIPM comparison BIPM.RI(II)-K1.Ho-166m of activity measurements of the radionuclide ^{166}Ho^{m} and the links for the 2000 international comparison APMP.RI(II)-K2.Ho-166m, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06016.
9. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.In-111 of activity measurements of the radionuclide ^{111}In, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06017.
10. Ratel G., Michotte C., Los Arcos J.-M., Activity measurements of the radionuclide ^{67}Ga for the CIEMAT in the BIPM comparison BIPM.RI(II)-K1.Ga-67, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06018.
11. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Cd-109 of activity measurements of the radionuclide ^{109}Cd and the links for the 1986 international comparison CCRI(II)-K2.Cd-109, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06019.
12. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Mo-99 of activity measurements of the radionuclide ^{99}Mo, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06020.
13. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Kr-85 of activity measurements of the radionuclide ^{85}Kr, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06021.

14. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.I-123 of activity measurements of the radionuclide ^{123}I and the links for the 1983 EUROMET.RI(II)-K2.I-123 comparison, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06022.

15. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.I-131 of activity measurements of the radionuclide ^{131}I, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06023.

16. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Cs-134 of activity measurements of the radionuclide ^{134}Cs and the links for the 1978 international comparison CCRI(II)-K2.Cs-134, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06024.

17. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Mn-54 of activity measurements of the radionuclide ^{54}Mn, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06025.

18. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Cs-137 of activity measurements of the radionuclide ^{137}Cs and the links for the 1982 international comparison CCRI(II)-K2.Cs-137, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06026.

19. Ratel G., Michotte C., Woods M.J., Update of the BIPM comparison BIPM.RI(II)-K1.F-18 of activity measurements of the radionuclide ^{18}F to include the NPL, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06027.

20. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Lu-177 of activity measurements of the radionuclide ^{177}Lu, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06028.

21. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Nb-95 of activity measurements of the radionuclide ^{95}Nb, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06029.

22. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Na-24 of activity measurements of the radionuclide ^{24}Na, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06030.

23. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Pb-203 of the activity measurements of the radionuclide ^{203}Pb, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06032.

24. Ratel G., Michotte C., Broda R., Listkowska A., Activity measurements of the radionuclide ^{60}Co for the RC, Poland in the ongoing comparison BIPM.RI(II)-K1.Co-60, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06033.

25. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ru-106 of activity measurements of the radionuclide ^{106}Ru, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06034.

26. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Na-22 of activity measurements of the radionuclide ^{22}Na, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06035.

27. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Sb-124 of activity measurements of the radionuclide ^{124}Sb, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06037.

28. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Sc-46 of activity measurements of the radionuclide ^{46}Sc, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06038.

29. Ratel G., Michotte C., Janßen H., BIPM comparison BIPM.RI(II)-K1.Ta-182 of activity measurements of the radionuclide ^{182}Ta, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06039.

30. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ru-103 of activity measurements of the radionuclide ^{103}Ru, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06040.

31. Ratel G., Michotte C., Reher D., BIPM comparison BIPM.RI(II)-K1.Sc-47 of activity measurements of the radionuclide ^{47}Sc and the links for the 1983 EUROMET.RI(II)-K2.I-Sc-47 comparison, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06001.

32. Ratel G., Michotte C., Bochud F.O., BIPM comparison BIPM.RI(II)-K1.Rn-222 of activity measurements of the radionuclide ^{222}Rn, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06002.

33. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Eu-152 of activity measurements of the radionuclide ^{152}Eu and the links for the international comparison CCRI(II)-K2.Eu-152, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06003.

34. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Sn-113 of activity measurements of the radionuclide ^{113}Sn, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06004.

35. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Tc-99m of activity measurements of the radionuclide ^{99}Tc^{m}, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06005.

36. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Sr-85 of activity measurements of the radionuclide ^{85}Sr, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06006.

37. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Se-75 of activity measurements of the radionuclide ^{75}Se and the links for the international comparison CCRI(II)-K2.Se-75, *Metrologia*, 2004, **41**, *Tech. Suppl.*, 06007.

6.3.2 BIPM reports

38. Allisy-Roberts P.J., Burns D.T., Berlyand V., Bregadze Y., Korostin S., Comparison of the standards of absorbed dose to water of the VNIIFTRI, Russia and the BIPM for ^{60}Co γ-rays, *Rapport BIPM*-2003/09, 2003, 12 pp.

39. Allisy-Roberts P.J., Burns D.T., Csete I., Comparison of the standards of absorbed dose to water of the OMH and the BIPM for ^{60}Co γ-rays, *Rapport BIPM*-2003/08, 2003, 11 pp.

40. Allisy-Roberts P.J., Burns D.T., Laitano R.F., Toni M., Bovi M., Revised comparison of the standards for air kerma of the ENEA-INMRI and the BIPM for ^{60}Co gamma rays, *Rapport BIPM*-2003/10, 2003, 11 pp.

41. Allisy-Roberts P.J., Toni M., Bovi M., Comparison of the standards for air kerma of the ENEA-INMRI and the BIPM for ^{60}Co gamma radiation, *Rapport BIPM*-2002/09, 2003, 10 pp.

6.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- BIPM Summer school, 21 July – 1 August 2003, to give a lecture on ionizing radiation dosimetry;
- NPL (United Kingdom), 22-24 October 2003, for the DTI Measurement Advisory Committee (MAC); 11–13 November 2003, for the review of the NPL ionizing radiation and acoustics programmes for the MAC;
- London (United Kingdom), 7 July 2003, to attend the Ionizing Radiation Health and Safety Forum; 22 January 2004, for an international prioritization meeting held by the MAC; 28 January 2004 and 30 June 2004, for the editorial board of the *Journal of Radiological Protection*;

23 April 2004, for a meeting concerning high radiation doses at the Department of Health (United Kingdom); 7-10 June 2004, MAC working groups on ionizing radiation and on acoustics; 16 June 2004, to present a paper on ionizing radiation at a meeting for radiation protection advisers;

- Vienna (Austria), 1-5 March 2004, to chair the 11th meeting of the Scientific Committee of the IAEA dosimetry programme;
- BNM-LNHB (France), 10 March and 4 May 2004, to attend their Conseil Scientifique;
- NEL (United Kingdom), 15-16 March 2004, for the MAC.

D.T. Burns to:

- Melbourne (Australia), 19-21 August 2003, to attend the Workshop on Recent Advances in Absorbed Dose Standards;
- Oxford (United Kingdom), 8-12 September 2003, to attend the meeting of the Main Commission of the ICRU;
- Helsinki (Finland), 6-7 November 2003, as the BIPM contact person on ionizing radiation and radioactivity at the EUROMET contact person meeting.

D.T. Burns and C. Kessler to Sydney (Australia), 25-29 August 2003, to participate in the World Congress on Medical Physics and Biomedical Engineering. D.T. Burns presented the paper "Calculation of the wall correction for ^{60}Co air kerma standards using PENELOPE" and C. Kessler the poster "Calculation of the wall correction factor for the BIPM air kerma standard for ^{137}Cs using the code PENELOPE."

C. Michotte to:

- BIPM Summer school, 21 July – 1 August 2003, to give a lecture on the metrology of radioactivity;
- Paris (France), 1-5 December 2003, to participate in the VERMI young researchers workshop on primary standardization methods.

S. Picard to:

- BNM-LNHB (France), 18 December 2003, to discuss calorimetry methods with Drs A. Ostrowsky and J. Daures;
- NPL (United Kingdom), 26 January 2004, to discuss calorimetry methods with Drs S. Duane and H. Palmans.

S. Picard and G. Ratel to NPL (United Kingdom), 27-28 January 2004, for a training course on "Scientific computing with Fortran 90/95".

6.4 Activities related to external organizations

P.J. Allisy-Roberts is the member of the MAC for ionizing radiation and acoustics and is a scientific member of the UK Ionizing Radiation Health and Safety Forum. She is also a member of an ICRU Report Committee, the BIPM representative on the IAEA SSDL Scientific Committee, a member of the editorial board of the *Journal of Radiation Protection* and a referee for *Physics in Medicine and Biology* and the *Bulletin du BNM.*

D.T. Burns is the BIPM representative at the ICRU and is the BIPM contact person at EUROMET for ionizing radiation and radioactivity. He is a referee for *Physics in Medicine and Biology* and for *Medical Physics*.

G. Ratel is the BIPM representative at the International Committee for Radionuclide Metrology (ICRM).

6.5 Activities related to the work of Consultative Committees

P.J. Allisy-Roberts is Executive Secretary of the CCRI and its three Sections, and of the CCAUV. She attended the CCRI RMO Working Group.

She and D.T. Burns are members of the CCRI(I) working groups on metrological equivalence (key comparisons) and on air kerma correction factors for cavity chambers.

G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, on key comparisons (attended with C. Michotte) and on measurement uncertainties.

C. Michotte is the contact person at the BIPM and *rapporteur* for the JCGM/WG1.

6.6 Visitors to the Ionizing Radiation section

- Dr S. Pommé (IRMM), 10 July 2003.
- Mr A. Pearce, Mr S. Judge and Prof. M. Cox (NPL), 5 August 2003.
- Mr A. Pearce and Prof. M. Cox (NPL), 22 September 2003 and 5 May 2004.
- Mrs M.G. Iroulart (BNM-LNHB), 28 September 2003.
- Drs Li Mo and D. Alexiev (ANSTO), 20 October 2003.
- Dr Y. Nedjadi (IRA), 8 December 2003.
- Dr T. Kurosawa (NMIJ/AIST), 15 December 2003.
- Mrs M.-C. Lépy, Mr P. Cassette (BNM-LNHB) and Mrs K.C. de Souza Patrão (Universidade Federal do Rio de Janeiro, Brazil), 5 March 2004.
- Mrs A.C. Bellanger and Mr C. Bellanger (BNM-LNHB), 8 April 2004.
- Dr M. Sahagia (IFIN), 6 May 2004.
- Dr M.-M. Bé (BNM-LNHB), 18 May 2004.

6.7 Guest workers

- Mrs C. Lim (KFDA), 17-30 November 2003.
- Mr F. Delaunay (in part) and E. Leroy (BNM-LNHB), 24 November – 5 December 2003.
- Dr K. Shortt (IAEA), 8-10 December 2003.
- Mr I. Jokelainen and Mr I. Aropalo (STUK), 9-13 February 2004.
- Mrs A. Gonzalez and Dr A. Brosed (CIEMAT), 12-24 March 2004.
- Dr E.A. Hult (NRPA), 7-8 April 2004.
- Mr L. Czap (IAEA), 21-25 June 2004.

7 CHEMISTRY (R.I. WIELGOSZ)

7.1 Ozone photometer comparison programme
(J. Viallon and R.I. Wielgosz; P. Moussay)

The BIPM is coordinating the ozone (ambient level) comparison (CCQM-P28). Fourteen laboratories have participated in the comparison since July 2003, each spending up to one week at the BIPM. Each laboratory's national or transfer standard has been compared against BIPM-SRP27. A further 13 laboratories are expected to participate in the comparison and measurements are foreseen to end in December 2004.

An informal comparison of the newly acquired ozone reference standard of the IMGC with the BIPM-SRP27 reference standard has been performed. The IMGC instrument was designed and built by the KRISS. The comparison has allowed the degree of equivalence of the reference standards to be determined. Possible sources of measurement bias were investigated, and have been addressed during the characterization of BIPM-SRP33. IMGC will participate in the CCQM-P28 pilot study in October 2004.

7.1.1 Statistical treatment of comparison results

A collaboration with Dr W. Bremser from BAM on the statistical treatment of the pilot study results was initiated in January 2004. The focus of the project is the use of the generalized least-squares method to compare measurement results of two ozone photometers. Dr W. Bremser has adapted the program B_Least, developed for use with ISO 6143, to compare ozone photometer measurements. The new version of the programme allows various correlations between the measurement results to be considered, and will correctly demonstrate how the number of measurement results affects the result of a comparison.

7.1.2 SRP characterization

The construction of BIPM-SRP33 at the BIPM was completed in July 2003. The optical bench was manufactured at the BIPM. The instrument was characterized by comparison with BIPM-SRP27 and found to be comparable within its calculated measurement uncertainty. The instrument has been used to investigate possible sources of bias in SRP measurements.

The accuracy of the temperature measurement in the SRP has been evaluated. A temperature gradient is evident along the gas cells within the instrument and has been measured in all SRPs maintained at the BIPM. The corresponding relative error in the measured value of the ozone mole fraction due to the temperature gradient has been shown to be as large as 0.5 %. A temperature control unit (TCU) to equilibrate the gas cell temperature has been designed and constructed at the BIPM. The TCU has been installed on BIPM-SRP31, 32 and 33 and shown to reduce the temperature gradient within the gas cells to less than 0.1 °C, reducing the bias in measured ozone mole fraction values to negligible levels.

The pressure difference in the gas cells of SRPs (within cell and between cell variations) has been verified. The maximum difference in pressure measured was consistent with the uncertainty budget currently in use.

The effect of optical design on the optical path length and, consequently, on the measured ozone mole fraction within SRPs has been investigated. The SRP design has been modified to allow the manual variation of the light beam alignment. In the current SRP design, the optical windows are perpendicular to the optical axis. Modified optical window holders have been designed and constructed with the windows a few degrees away from perpendicular. The redesigned optical system has confirmed the presence of multiple reflections within the gas cells, resulting in relative differences of 0.5 % in the ozone mole fraction measurements. Further characterization of the optical path length is limited by the poor collimation of the beam from the Hg lamp. A feasibility study on the incorporation of a laser based light source into the SRP has been completed.

7.2 Primary NO_2 gas standard facility

(M. Esler and R.I. Wielgosz; P. Moussay)

A primary gas standard facility for the dynamic preparation of nitrogen dioxide gas standards is being developed. The facility is based upon a magnetic suspension balance system, which was replaced by the manufacturer in April 2003. The new system has been tested, and analysis of the Allan variance of time series measurements has confirmed that it now meets the required stability specifications. Full software control of the facility is now underway with the development of a dedicated program for communications, data acquisition and automation. The development of the facility will continue during the following period. The completed facility will

ultimately act as a primary reference for NO_2 mass fraction measurements for gas-phase titration.

7.3 **Gas phase titration facility** (M. Esler and R.I. Wielgosz)

A gas-phase titration (GPT) facility as a second, potentially, primary method for ozone concentration measurements has been constructed. The system employs the mass-flow-controlled dynamic dilution of high-concentration nitrogen monoxide gas standards. Changes in NO concentration are monitored with a chemiluminescence analyzer and compared with the loss of ozone determined from UV absorption. The system has been fully automated. The first version of this facility relied on calibrated mass flow controllers (MFC) for values of gas flow. An examination of the uncertainty budget for the measurement results revealed that the MFCs are a dominant contributor to the overall uncertainty of the measurement result. Four molblocs have been purchased and are being integrated into the system to allow real time measurement of gas flow at considerably reduced uncertainty. Validation of the facility is currently underway. It is planned that the redesigned facility will participate in CCQM-P28 (ozone, ambient level).

7.4 **NO gas standard comparison facility** (M. Esler and R.I. Wielgosz)

A facility for the comparison of NO gas standards with nominal amount fractions of 50 μmol/mol has been established for the comparison of NO gas standards to be used for gas-phase titration. The behavior of two NO analyzers based on independent detection principles, UV absorption and chemiluminescence, has been analyzed. The uncertainty in the measurement results was reduced by optimizing the experiment design to minimize the Allan variance on time series measurements of NO amount fraction. Calibration curves were analyzed with generalized least-squares (GLS) regression, allowing the uncertainty in both axes to be taken into account. It has been demonstrated for the first time that using this measurement procedure, that NO gas standards can be analyzed with a measurement uncertainty arising from their analysis which is of the same order of magnitude as the uncertainty in their value determined from their gravimetric preparation. A suite of 13 gravimetric primary reference NO/N_2 gas mixtures has been purchased, from two different NMIs, together with a set of commercial secondary NO/N_2 mixtures for use in the GPT system. A procedure for the labeling of the secondary standards relative to the primary

standards is being evaluated. The completed facility will be used to ensure that the measurements of the amount fraction of NO in the GPT system are traceable to primary gravimetric gas standards. In addition, the BIPM has recently proposed a CCQM pilot study which would begin in 2005 on the comparison of NO gravimetric mixtures, using the NO facility. Twelve NMIs have expressed interest in participating in such a comparison. A protocol for the proposed study is in preparation.

7.5 **Composition of air** (M. Esler and R.I. Wielgosz)

The KRISS have undertaken a determination of the mole fraction of argon in air in order to resolve the discrepancy in methods for the determination of air density. The importance of these measurements to mass metrology was presented to the CCQM Working Group on Gas Analysis by the BIPM. The KRISS value of 9.331 mmol/mol has been reported with a combined standard uncertainty of only 3 μmol/mol. The use of this value removes the discrepancy between methods for the determination of air density. Two papers reporting the details of the argon amount measurement and its consequences for mass metrology have been prepared by the KRISS and the BIPM Chemistry and Mass sections, and were submitted in June 2004 for publication in *Metrologia*.

7.6 **Organic analysis programme** (R.I. Wielgosz)

A detailed BIPM work programme in the field of organic pure substances was presented to the CCQM Working Group on Organic Analysis in September 2003 and the CCQM in April 2004.

The long-term aim of the programme is to enable the BIPM to engage in and support the CCQM international programme of purity assessment comparisons and contribute to the development of robust approaches and methodologies for the determination of purity. This will require the extension of the CCQM-P20 series of comparisons for purity determination, the establishment of BIPM laboratory facilities to support these activities, the establishment of international liaisons to support and promote the programme. The programme will thereby ensure that the international comparisons of the CCQM provide agreed and documented methodologies for purity determination. The programme will not require the BIPM to produce reference materials.

In the initial five year period, the BIPM will establish its programme of purity assessment of select organic pure substances, and link this to the CCQM series of organic substance purity comparisons. In considering pure organic substances for study, the BIPM has prioritized the requirements in laboratory medicine for pure clinically relevant analytes, which would be required for the establishment of reference measurement systems. The initial period of the programme will therefore focus on the purity assessment of clinically relevant steroids and therapeutic monitored drugs. The BIPM has established collaborative projects with the LGC and the NMIJ/AIST to coordinate comparisons on these substances. This will enable the programme to be linked to the programme of comparisons of the CCQM and relevant to the activities of the JCTLM.

The BIPM organic substance purity laboratory is currently being established, and two scientists have been recruited and will join the staff in the autumn of 2004.

7.7 Publications, lectures, travel: Chemistry section

7.7.1 External publication

1. Griffith D.W.T., Esler M.B., Steele L.P., Reisinger A., Non-linear least-squares: high precision quantitative analysis of gas phase FTIR spectra, *Proc. 2nd Int. Conf. Advanced Vibrational Spectroscopy*, 23-29 August 2003, Nottingham, United Kingdom, 2003, 153.

7.7.2 Travel (conferences, lectures and presentations, visits)

M. Esler to:

- University of Nottingham (United Kingdom), 24-29 August 2003, to attend and present poster at the 2nd International Conference on Advanced Vibrational Spectroscopy;
- BNM-LNE, Paris (France), 8-9 September 2003, to attend the EUROMET Workshop on Gas Purity;
- University of Wollongong (Australia), 12 February 2004, to give a seminar on the BIPM chemistry programme;
- NARL/AGAL (Australia), 13 February 2004, to give a seminar on the BIPM chemistry programme;

- BNM-LNE, Paris (France), 13-14 April 2004, to attend the Metropolis workshop: State of the art and new trends in the use of reference materials for environmental monitoring and analysis.

P. Moussay to the BNM-LNE, Paris (France), 11 March 2004, to perform a modification on the SRP24.

J. Viallon and P. Moussay to UBA, Langen (Germany), 22-25 March 2004, to install SRP19 in their laboratory and reproduce the comparison with BIPM-SRP31 performed in BIPM.

R.I. Wielgosz to:

- WHO, Geneva (Switzerland), 26-27 July 2003, to participate in a WHO informal consultation on the preparation, characterization and establishment of WHO international standards and other biological reference materials;
- NIST, Gaithersburg (United States), 4-5 September 2003, to participate in the JCTLM Working Group 1 meeting on reference materials and reference measurement procedures;
- CENAM, Querétaro (Mexico), 11-12 September 2003, to participate in the CCQM Organic Analysis Meeting and present the BIPM Organic Analysis Programme;
- VNIIM, St Petersburg (Russian Fed.), 1-3 October 2003, CCQM Gas Analysis Meeting and present thus use of GLS for ozone reference standard comparisons, and progress with CCQM-P28;
- WHO, Geneva (Switzerland), 6-7 October 2003, to participate in a WHO working group on international reference preparations for testing diagnostic kits used for the detection of HBsAg and anti-HCV antibodies;
- NIST, Gaithersburg (United States), 8-9 January 2004, to draft the JCTLM Working Group 1 quality manual as part of the "Quality and Implementation Group";
- Sofia (Bulgaria), 10-13 February 2004, to attend the EUROMET Metchem plenary and Gas Analysis Working Group meeting and present the BIPM organic and gas analysis programmes and JCTLM activities;
- IAEA (Vienna), 17 February 2004, for a meeting of the IUPAC Analytical Chemistry Division and IUPAC Working Party for Harmonization of Quality Assurance and present a lecture of "Key

Comparison, the MRA and CMCs: An International Measurement Infrastructure";

- WHO, Geneva (Switzerland), 26-27 February 2004, for the WSC High-level Workshop on International Standards for Medical Technologies;
- Budapest (Hungary), 5 March 2004, to represent the BIPM at the International Agency Meeting (for organizations working in the field of analysis and sampling of food);
- Chicago (United States), 8-11 March 2004, to present the International Mutual Recognition Arrangement at PITTCON 2004;
- London (United Kingdom), 5-6 April 2004, for a meeting on organic pure substance reference materials at the LGC (Teddington), and a meeting at the Food Standards Agency on reference values for proficiency testing scheme materials;
- WHO, Geneva (Switzerland), 7-8 June 2004, to participate in a WHO Consultation on Global Measurement Standards and their use in the *in vitro* Biological Diagnostic Field;
- IRMM, Geel (Belgium), 28 June 2004, to present "Towards an international measurement infrastructure for Chemical Metrology" at a meeting on Establishing Metrology Infrastructure in South Eastern European Countries;
- ICC, Geneva (Switzerland), 30 June 2004, to represent the BIPM at the 27th session of the Codex Alimentarius Commission.

7.8 Activities related to external organizations

R.I. Wielgosz is the BIPM representative to the World Meteorological Organization (WMO) and the World Health Organization (WHO). He represents the BIPM and CCQM at ISO REMCO. He is a member of the editorial board of *Accreditation and Quality Assurance*.

7.9 Activities related to the work of Consultative Committees

R.I. Wielgosz is the Executive Secretary of the CCQM, and a member of its working groups on gas and organic analysis.

A workshop on "Comparability and Traceability in Food Analysis", was organized at the BIPM, and a summary of the workshop was published in *Accreditation and Quality Assurance* (2004, **9**, 521-522).

M. Esler and J. Viallon are members of the CCQM Working Group on Gas Analysis.

7.10 Activities related to the JCTLM

R.I. Wielgosz is Secretary of the Joint Committee for Traceability in Laboratory Medicine, JCTLM, and a member of its review team on "Quality Systems and Implementation".

The first meeting of the Executive Committee was held at the BIPM, following the signing of a declaration of co-operation between the CIPM, IFCC and ILAC, formally establishing the joint committee and inviting organizations with technical competence in the field to participate in its activities.

A JCTLM list of higher order reference materials and measurement procedures has been published on the BIPM website. This first list refers to well-defined chemical entities or internationally recognized reference method-defined measurands. The reference materials and measurement procedures included in this category are those that provide values that are traceable to SI units, e.g., electrolytes, enzymes, drugs, metabolites and substrates, non-peptide hormones and some proteins.

7.11 Visitors to the Chemistry section

- Mrs P.M. Gomez and Mr D.G. Madruga (ISCIII), 8-12 September 2003.
- Mrs M. Jansee van Rensburg (CSIR-NML), 11 September 2003.
- Mr F. Lagler (EC-JRC ERLAP), 22-25 September 2003.
- Mrs S. Goldthorp (Environment Canada), 20-24 October 2003.
- Dr D.W. Zickert and Mr D. Schwaler (METAS), 17-21 November 2003.
- Mrs S. Havrlantova (CMI), 20 November 2003.
- Dr J.C. Woo (KRISS), 1-5 December 2003.
- Dr W. Bremser (BAM), 15-16 January 2004.
- Dr M.P. Sassi and Mr E. Malgeri (IMGC-CNR), 26-30 January 2004.
- Mrs T. Macé and Mr C. Sutour (BNM-LNE), 2-6 February 2004.
- Mr D.V. Rumyanstev (VNIIM), 16-20 February 2004.
- Mr J. Walden (FMI), 1-5 March 2004.
- Dr C. Zellweger (WCC-EMPA), 15-19 March 2004.

- Drs H. Moody and K. Jaeger (NCSLI), 23 March 2004.
- Mrs M. Froelich and Mr A. Wolf (UBA Austria), 29 March – 2 April 2004.
- Mrs S. Langer and Mr B. Magnusson (SP), 3-7 May 2004.
- Mr B. Sweeney (NPL), 25-28 May 2004.
- Mrs B. Frigy, Mrs I.G. Váraljai and Mr D. Laszlo (IEM-DEP), 7-11 June 2004.
- Mr V. Stummer (UBA Germany), 21-25 June 2004.
- Dr C. Murthy (CMS-NML/ITRI), 29 June 2004.

7.12 Guest worker

- Dr J. Norris (NIST), 16 June – 1 August 2003.

8 THE BIPM KEY COMPARISON DATABASE, KCDB (C. THOMAS)

8.1 Information registered in the KCDB (S. Maniguet and C. Thomas)

Appendix B of the database now covers some 570 key and supplementary comparisons conducted under the auspices of the CIPM or of the RMOs; 141 of which have had their results published via the KCDB by 1 June 2004. The ongoing BIPM key comparisons in electricity are regularly updated with the results of new bilateral comparisons carried out between the BIPM and some national metrology institutes. Since October 2002, results have been approved and published for 49 of the 59 ongoing BIPM key comparisons on radionuclide activity conducted within the framework of the International System of Reference (SIR).

The results of 15 RMO key comparisons (7 conducted by APMP and 8 by EUROMET) are linked to those of the corresponding CC key comparisons; the full sets of degrees of equivalence are published via the KCDB. The same type of linkage is also carried out for the 8 key comparisons of radionuclide activity conducted under the auspices of CCRI(II), and linked to the corresponding ongoing BIPM SIR key comparisons. New results approved

by CCs are still communicated to the BIPM for publication via the KCDB at a mean rate of about one per week.

Appendix C contains some 15 000 CMCs, covering eight subject areas of metrology (acoustics, ultrasound and vibration, chemistry, electricity and magnetism, length, mass and related quantities, photometry and radiometry, ionizing radiation, and thermometry). The range of uncertainty that characterizes one given CMC can additionally be described by an uncertainty table, the column and row headings of which contain the values taken by two physical quantities (or parameters) involved in the CMC. This makes it possible to deliver much more precise information. The total number of uncertainty values published in the Appendix C can now be estimated to be over 30 000.

Hundreds of CMCs are currently in preparation in the fields of time and frequency, thermometry, and also ionizing radiation (mainly radioactivity).

8.2 Progress in the development of the KCDB system
(S. Maniguet and C. Thomas)

Following the publishing on the Web of the new KCDB website on 4 March 2003, no major restructuring was needed this year. However, we introduced three improvements to respond to users' requirements.

- The approval dates are shown for CMCs published after 24 May 2004.
- The "Uncertainty tables" facility (see above), implemented at the beginning of 2004, allows a better description of the declared uncertainties.
- The html pages resulting from a selection among the items proposed by the Appendix C search engines have been attributed an absolute URL address since 7 June 2004. This allows the user to copy the address window in the web browser and save it or send it so that the same search does not have to be repeated every time.

As in previous years, we have resolved these technical matters with an outside company based in France, whose advice and products make it possible to profit from the best available techniques using optimal programming methods. Any modifications in design, however, are handled within the BIPM.

8.3 The KCDB and the BIPM Quality System
(S. Maniguet and C. Thomas)

The KCDB work is described in eight procedures that successfully passed the BIPM Quality System internal review on 23 March 2004. Six of these describe the technical aspects of the entry of information into the databases that compose the KCDB; they are kept in restricted access for some BIPM members only, and are saved on CDs placed in individual offices. The two others deal with the formal authorization processes needed before launching data on the Web; they are available on the BIPM intranet and may be diffused outside the BIPM.

8.4 Publicizing the KCDB (S. Maniguet and C. Thomas)

Following requests from JCRB and CC meetings, we try to publicize the KCDB as often as we can through the publication of papers in diverse newsletters and the presentation of posters at congresses. For example, we demonstrated the KCDB, live on the internet, on the NIST stand at the conference PITTCON'2004 which gathers some 25 000 international experts in the field of chemistry. Some 300 KCDB leaflets were also distributed at this occasion.

In addition, we distributed the first issue of the "*KCDB Newsletter*" to about 1000 email addresses on 16 June 2004, and made it available on the KCDB website. We intend to issue such Newsletters twice a year, in June and in December. They may provide a good place for communication on matters relevant to specific fields of metrology in the context of the MRA.

8.5 Travel (conferences, lectures and presentations, visits)

C. Thomas to:

- the Institut de France, Paris (France), 22 September 2003, 24 November 2003, 26 January 2004, 7 April 2004 and 14 June 2004, for meetings of the Working Group of the Académie des Sciences "Unités de base et constantes fondamentales";
- Paris (France), 2-3 October 2003, to attend the "Colloque Pierre Jacquinot" held at the CNRS;
- Chicago (Illinois, United States), 8-12 March 2004, invited by NIST to share their stand at PITTCON'2004 in order to present the BIPM key comparison database.

8.6 Activities related to external organizations

On 1 September 2003, C. Thomas was appointed as "Chargée de mission auprès de Monsieur le Secrétaire perpétuel de l'Académie des Sciences de Paris". In this context, she acts as the Scientific Secretary of the Working Group of the Académie des Sciences "Unités de base et constantes fondamentales".

8.7 Activities related to the work of Consultative Committees

C. Thomas is the Executive Secretary of the CCU.

C. Thomas attended the following meetings:

- CCL Working Group on Dimensional Metrology, 8-9 September 2003;
- 11th CCL, 10-11 September 2003;
- RMOs Working Group on Ionizing Radiation, 25-26 September 2003;
- CCEM Working Groups, 3-7 November 2003;
- 16th CCTF, 1-2 April 2004;
- 10th CCQM, 22-23 April 2004;
- 16th CCU, 13-14 May 2004.

C. Thomas also acted as Scientific Secretary of the BIPM Metrology Summer School 2003 held at the BIPM from 21 July to 1 August 2003.

9 THE JOINT COMMITTEE OF THE REGIONAL METROLOGY ORGANIZATIONS AND THE BIPM, JCRB (I. CASTELAZO)

9.1 End of the transition period

Paragraph 11.3 of the CIPM MRA defined a transition period extending from the signature of the MRA in October 1999 until such time as the first round of key comparisons has been completed and the Quality Systems referred to in Paragraph 7.3 have been put in place. The JCRB interpreted the end of this period as 31 December 2003, and asked the RMOs to report on the status of NMI Quality Systems by 5 April 2004. At its 12th meeting, held in Querétaro

(Mexico) in May 2004, the JCRB reviewed the reports submitted by the RMOs and found that most NMIs have successfully implemented a Quality System that underpins the confidence in their CMCs published in Appendix C. Nevertheless, some RMOs indicated that they still needed to complete some final reviews and that a few NMIs have requested additional time to finish the implementation of their Quality System. The JCRB established a final deadline of 31 December 2004 for all NMIs to have a fully implemented Quality System supporting their published CMCs and asked the RMOs to send a report to the BIPM by 31 March 2005. Any CMCs that are not covered by an approved Quality System after such time will be deleted from Appendix C.

The JCRB also noted that the Consultative Committees have defined appropriate cycle times for all key comparisons, and that the large number of key comparisons currently available in the KCDB provides sufficient confidence to declare an end to the transition period. A related document was approved by the JCRB at its 12th meeting, specifying the process and responsibilities to monitor the impact of key and supplementary comparison results on CMC claims.

9.2 Interpretation and revision of CIPM MRA – related documents

At its 92nd meeting, in October 2003, the CIPM approved proposals from the JCRB for modifications to the Technical Supplement of the CIPM MRA. These changes concern paragraph T.7, stating that unresolved inconsistencies resulting from supplementary comparisons will be noted in Appendix C, and paragraph T.10, clarifying that supplementary comparisons are only carried out by RMOs.

At the same meeting, the CIPM approved a modification to paragraph 12 of the *Guidelines for CIPM key comparisons*, noting that supplementary comparisons should only be "inspired" by them but that they do not need to follow exactly the same procedures; for example, the calculation of a reference value is not required for supplementary comparisons. Finally, a note was added to paragraph 11 to take into account the electronic publishing of comparison results.

9.3 Inter-regional review procedures

JCRB procedures have been revised with the objectives of improving the efficiency of the process, and assuring CMC declarations that are uniform and technically correct. A time limit was included in the procedure for the approval of posted CMCs, after which they will be published in Appendix C in the absence of objections and if, at least, one RMO indicates its consent.

A document was approved at the 11th meeting of the JCRB which clarifies the chain of responsibility to ensure that CMC claims made by an NMI are consistent with the results obtained in key and supplementary comparisons. The instructions for drawing up CMC Excel files now include a procedure for specifying the range and uncertainty of CMCs and forbids any form of ambiguous declaration.

9.4 New Executive Secretary

On 31 October 2003, Dr Angela Samuel concluded a successful two year tenure as Executive Secretary of the JCRB and returned to her home organization, NML-CSIRO, in Sydney (Australia). Dr Ismael Castelazo started working as the designated Executive Secretary on 22 September 2003 and benefited from a six week overlap with Dr Samuel.

9.5 Publications, lectures, travel: JCRB

9.5.1 Document revisions accepted by the CIPM

1. Technical Supplement of the CIPM MRA.
2. Guidelines for CIPM key comparisons.

9.5.2 New JCRB documents

Available at: www.bipm.org/en/committees/jc/jcrb/documents.html

1. Activities of the JCRB: 1999-2003.
2. Primer for TC/WG chairpersons on the CMC review process, *JCRB-11/6(3).*
3. Monitoring the impact of key and supplementary comparison results on CMC claims, *JCRB-11/7(a).*

4. CMC specification procedure, *JCRB-12/06(2)*, included in the Instructions for drawing up CMC excel files, *JCRB-6/6.*
5. Supplementary comparisons – definition, *JCRB-11/8(5)_rev.*

9.5.3 Revised JCRB documents

Available at: www.bipm.org/en/committees/jc/jcrb/documents.html

1. Terms of reference for CC Working Groups on CMCs, *JCRB-11/6(2).*
2. End of transition period of the CIPM MRA – Review of published CMCs, *JCRB-11/7.*
3. Flowchart of the CMC review process, *JCRB-12/06a_rev.*
4. Flowchart of the key comparison process, *JCRB-11/2(a).*
5. Flowchart of the supplementary comparison process, *JCRB-8/19(c)_rev.*

9.5.4 Travel (conferences, lectures and presentations, visits)

I. Castelazo to:

- Vienna (Austria), 2-5 December 2003, for the UNIDO General Assembly and the Expert Group Meeting on Mutual Recognition Agreements. The JCDCMAS Background paper "Building trade capacity and technical infrastructure in developing countries" was distributed at the Round Table 3 on "Making trade work for the poor – Stimulating the real economy's response";
- BIPM, 3 March 2004, for the BIPM/OIML/ILAC meeting, and 4 March for the BIPM/ILAC meeting;
- Geneva (Switzerland), 26 March 2004, for the JCDCMAS meeting;
- Querétaro (Mexico), 3-7 May 2004, for the 12th JCRB meeting and the SIM meetings of its Quality System Task Force as well as its Technical and Professional Development Committees.

9.6 Activities related to external organizations

The JCRB Executive Secretary served also as the Executive Secretary for the Joint Committee on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization (JCDCMAS) until March

2004. This function was carried out by Angela Samuel until October 2003 and by Ismael Castelazo from that time until March 2004. Both Executive Secretaries collaborated in the preparation of the background document on Metrology, Accreditation and Standards, presented by the JCDCMAS at the UNIDO General Assembly, held in Vienna in December 2003. At the last JCDCMAS meeting, held in Geneva, in March 2004, it was decided that the host organization of each annual meeting will serve as the Executive Secretary for that year. Currently, this post is held by the International Electrotechnical Commission (IEC).

9.7 Activities related to the work of Consultative Committees

A. Samuel and I. Castelazo attended the 11th JCRB meeting, 6-7 October 2003.

I. Castelazo attended the following meetings:

- CCRI RMO Working Group on CMCs, 25-26 September 2003;
- CCEM 4th RMO Electricity and Magnetism Technical Committee/ Working Group Chairpersons Meeting, 3 November 2003;
- CCQM Working Group on CMCs, 19-20 April 2004.

9.8 Visitors to the JCRB

- Ing. A. Bigot (Ministry of Education, Science and Technology, Argentina), 10 December 2003.
- Mr S. Kajane (Botswana Bureau of Standards), 22 March 2004.
- Fís. C. Sánchez Morales (SIC), 1 June 2004.
- Dr A. Valqui (PTB) and Mr U. Hillner (BMZ), 8 June 2004.

10 QUALITY SYSTEM (R. KÖHLER)

10.1 Liaison to ISO and ILAC (R. Köhler)

The BIPM recognizes the importance of a closer collaboration and an open exchange of information with ISO and ILAC in support of the BIPM-ILAC Memorandum of Understanding.

A joint BIPM-ILAC working group has been set up, and the group met in March 2004 at the BIPM. Both organizations will prepare a joint paper on fundamental issues and the national and regional roles of NMIs and accredition bodies, considering the new economic realities. Such a close collaboration will improve the consistency of comparisons at the accredited laboratory level to those at the NMI level.

The BIPM now also takes a more active role in a number of ISO working groups, namely on vocabulary, quality in metrology and accreditation issues. The aim here is to state the BIPM's standpoint *vis-à-vis* to ISO, and to alert the BIPM on any work at ISO which may have an impact on the BIPM or its stakeholders.

10.2 Travel (conferences, lectures and presentations, visits): Quality System

R. Köhler to:

- Turin (Italy), 9-11 September 2003, to participate in the AMCTM conference;
- IPQ, Caparica (Portugal), 27-28 January 2004, for a meeting of the EUROMET QS-Forum;
- ISO, Geneva (Switzerland), 6 April 2004, for discussions with the Head of ISO CASCO, Mr G. Drake;
- Kuala Lumpur (Malaysia), 12-14 April 2004, for a joint APMP-SIM meeting on Quality Systems;
- PTB, Berlin (Germany), 13-14 May 2004, for an INTMET meeting;
- NMIJ/AIST, Tsukuba (Japan), 24-26 May 2004, for the preparation of the joint BIPM-NMIJ workshop on the impact of IT on metrology and discussions with the Quality Management at the NMIJ/AIST;
- ISO, Geneva (Switzerland), 29 June 2004, for a meeting of ISO WG 25.

11 SPECIAL PROJECTS (M. STOCK)

11.1 Calculable capacitor (F. Delahaye, R. Goebel, J. Sanjaime, M. Stock, L. Vitushkin and T.J. Witt)

The BIPM has started a co-operative project with NML-CSIRO (Australia) to develop a new advanced version of the calculable capacitor. The new version is based on advanced design techniques and improved technology developed since the original calculable capacitor was invented and constructed by NML in the 1960s. The BIPM and the NML-CSIRO will collaborate to design and construct two calculable capacitors, one each for the BIPM and the NML-CSIRO, with the objective of an uncertainty of 1 part in 10^8. The completion date is estimated as 31 October 2006.

BIPM's main contribution will be an optimized interferometer for the length measurement and the construction of a number of mechanical pieces.

During the period October 2003 to March 2004, a measuring jig which will serve to test the quality of the electrode rods has been manufactured at the BIPM workshop. The straightness of the electrodes is crucial for a good performance of the instruments.

Special software is in development (in collaboration with A. Lukin and V. Grikurov from St Petersburg) for the calculation of the interference patterns in a multi-beam interferometer in transmission and reflection. This software will make it possible to simulate the interference patterns for arbitrary wave fronts of the incident beam and various shapes and reflection coefficients of the mirrors. It will also be possible to simulate the misalignments of the optical components of the interferometer.

The development of a compact iodine-stabilized modulation-free Nd:YVO_4/KTP laser at 532 nm for a laser displacement interferometer is in progress (with O.A. Orlov, VNIIM, St Petersburg).

11.2 Watt balance (R.S. Davis, F. Delahaye, H. Fang, A. Picard, T.J. Quinn, D. Reymann, S. Solve, M. Stock, L. Vitushkin and T.J. Witt)

The work during the recent months has focused on the conception of the magnetic circuit and the traveling coil. We have also studied the different techniques which will be required to make the necessary alignments of the system.

The magnetic circuit will be based on permanent magnets producing a radial field. Finite element calculations were made for two different geometries: an open circuit, similar to the BNM-LNE system, with the annular magnet and the air gap accessible from outside the circuit, and a closed, symmetrical circuit, with the magnets and the air gap inside the system. The symmetrical system seems to be the most advantageous, because the air gap is screened by the surrounding iron structure from external fields and the uniformity of the flux density within the air gap is greater due to the high symmetry of the circuit. The efficient screening from external fields due to the closed circuit should allow movement of the magnetic circuit instead of the coil in order to generate the induced voltage during the velocity mode. The closed circuit is also more compact than the open one. We have started discussions with a specialized engineering company on the fabrication of such a system. A first dimensioning of the moving coil has been made. We have started to make a model of the coil to determine its thermal and electrical properties.

We believe that it is essential, for the successful operation of a watt balance, to fully understand and control the alignment of the coil within the magnet and of the magnet to the vertical. An alignment strategy was developed which will be tested at room temperature. A precision solenoid will serve as a reference to align the traveling coil horizontally. The magnet will then be centered on the coil and aligned horizontally by measuring the voltage induced by small oscillations of the coil and by measuring the torque when a current flows through the coil.

To generate the velocity mode, two designs were studied: one acting on the magnetic circuit using flexure levers and the other by moving the coil and the mass by using an electrostatic drive mechanism in the coil suspension. The second model will be built and tested in the second half of this year.

We made a study on the effects of eddy currents resulting from the movement of the current-carrying-coil within the magnet. This problem is a consequence of our concept to carry out the weighing and moving experiments simultaneously. The typical forces can be relatively large at cryogenic temperatures (of the order of 1 μN, which is an apparent mass change of 0.1 mg) but should be symmetric with respect to the direction of coil movement and therefore cancel for a whole cycle of measurements.

The temperature coefficient of the remanence of a special variety of SmCo magnets was measured to verify the very low coefficient, within $+50 \times 10^{-6}\ K^{-1}$ and $-50 \times 10^{-6}\ K^{-1}$, given by the manufacturer. The published value was confirmed, thus opening the perspective of constructing a magnet

circuit with a very low temperature coefficient. This measurement was doubly interesting because magnets of the same material are used to servocontrol the FB-2 balance developed by the Mass section. Details can be found in *Rapport BIPM*-2004/04, available on the BIPM internet pages under recent publications of the Mass section.

11.3 Travel (conferences, lectures and presentations, visits): Special projects

R. Goebel to NML-CSIRO, Lindfield (Australia), 27-30 November 2003, visit and discussions of the calculable capacitor.

M. Stock to:

- BNM-LNE, Trappes (France), 18 February 2004, for discussions on watt balance and laboratory visits, accompanied by R.S. Davis and A. Picard;
- CEDRAT, Grenoble (France), 6-7 April 2004, to discuss a future contract for the fabrication of the magnetic circuit for the watt balance, accompanied by R.S. Davis and A. Picard;
- NIST, Gaithersburg (United States), 10-14 May 2004, to visit the NIST watt balance, accompanied by A. Picard;
- London (United Kingdom), 26 June – 2 July 2004, for the CPEM conference and the CCEM workshop on monitoring the stability of the kilogram, accompanied by R.S. Davis and A. Picard.

M. Stock and S. Solve to the BNM-LNE, Paris (France), 30 June – 1 July 2003, to participate at the "Watt Balances Technical Meeting".

11.4 Visitors: Special projects

- Dr F. Alves (SATIE, Cachan), 15 December 2003, for discussion on a magnetic circuit for the watt balance.
- Dr L. Érard (BNM), 24 February 2004, for discussion on the calculable capacitor project.
- Dr Y. Miki (NMIJ/AIST), 16 March 2004, for discussion on the BIPM watt balance.

12 PUBLICATIONS AND INFORMATION TECHNOLOGY
(P.W. MARTIN*, then J. WILLIAMS**)

12.1 Reports of the CIPM and Consultative Committees
(P.W. Martin*, J.R. Miles, C. Thomas and J. Williams**; D. Le Coz)

Since July 2003 the following have been published:

- *Director's Report on the Activity and Management of the BIPM (2003)*, 2004, **4**, 239 pp.
- *International Committee for Weights and Measures*, 91st meeting (2002), 2003, **70**, 213 pp.

Note: all scientific publications are listed in the appropriate sections of the report.

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees are published in their original language on the BIPM website. Full bilingual printed versions in French and English no longer appear.

12.2 *Metrologia* (P.W. Martin*, J.R. Miles and J. Williams**; D. Saillard)

Since the beginning of 2003, *Metrologia* has been produced in conjunction with Institute of Physics Publishing (IOPP) Ltd., the publishing arm of the Institute of Physics. In the new arrangement, manuscripts are still submitted to the editor based at the BIPM who is responsible for finding appropriate referees, and taking decisions as to the relative merits of a particular manuscript using the reports of the referees. Once a submission has been accepted for publication by the editor, usually after revision which is the responsibility of the editor at the BIPM, it is sent to IOPP for copy editing and printing. The proofs are dispatched by IOPP to the author, who returns any corrections directly to IOPP. Finally, the printed journal is dispatched to subscribers by IOPP. In addition to appearing in the printed journal, all submissions that have been accepted are made freely available for one month on the *Metrologia* section of the website for IOPP:

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* Until 31 January 2004.
** From 1 February 2004.

(www.iop.org/EJ/journal/Met).

The technical details of the production of *Metrologia* between the BIPM and IOPP are working extremely well. The journal appears on time and we benefit from the extensive marketing network of IOPP to assist in maintaining the subscriptions levels of the journal at a time when subscription levels are falling for the majority of technical scientific journals. Special issues of the *Metrologia* are still organized by an invited specialist editor in co-operation with the editor at the BIPM. Volume **40** of *Metrologia* was published in 2003. Over the last year, there have been two special issues of *Metrologia*: one on mass, and the other on density.

12.3 **Information Technology** (L. Le Mée, J.R. Miles; G. Petitgand)

The biggest single event in the Publications section over the last year has been the launch of a new website for the BIPM. This new website went "live" just before the CGPM in October 2003 and represents the first professionally designed website for the BIPM, with a fully integrated content management system. The new website is hosted on two servers which allow for load balancing. In October 2003, there were approximately 23 000 visitors over the course of the month. Since this opening, the number of visitors has steadily increased and we are presently receiving just over 2000 visitors each day. Since the opening of the new site, about a third of the visitors have been from the United States and about a quarter from Western Europe.

Visitors to the new website (www.bipm.org) will find over 3000 pages of information, including all the Resolutions of the CGPM (which receive about 6000 hits each month), and the text of the SI Brochure. Interestingly, the .pdf version of the SI Brochure is currently being downloaded over 2000 times per month; this rate of downloading is approximately equal for both the French and English versions. This interest in the SI Brochure implies that about 10 % of those who come to the BIPM website wish to consult the pages relating to the SI.

The new website is fitted with a search engine and over an eight month period the twenty most requested search items (apart from the names of individual staff members, where two appeared in top twenty) were: a number of the base units of the SI, 'summer school', 'uncertainty', GUM, 'conversion', 'CMC', UTC, 'air density', and SI units. Two of the most frequently used search facilities cover the BIPM's collection of 'useful links'

and the database of articles published in *Metrologia*. Another widely accessed tool is the search over the websites of the laboratories participating in the MRA.

The website also serves as a means of communication for the members of the Consultative Committees; documents relevant to their meetings are posted on the appropriate part of the website and are accessed my members via a password. In this way, we are able to economize on mailing large amounts of paper to members, who are able to consult documents electronically. Such a system of posting working documents for meeting on the website is working well and there are presently 1200 working documents relating to the Consultative Committees and about 700 working documents relating to Working Groups on the various sections of the website for the Consultative Committees.

Our internet site is now our most sophisticated and widely accessed tool for promoting our activities, superseding print publications. The website (professionally designed and well managed and maintained) is continually evolving and increasing in size and complexity; indeed, it has become the vehicle for projecting our corporate identity to the outside world. It is through our website that we are improving the services we provide to stakeholders.

This year saw the replacement, by the IT group, of the central server of the BIPM's information technology system, which had been in place since 1998. The new server has a larger memory and offers a better performance. Another change is that an important part of the software hosted on the new server is Open Source; that is, software that is freely available.

This year has seen an unprecedented increase in the amount of unsolicited emails (SPAM emails) arriving at the BIPM. Indeed, at present about 75 % of the, on average, 1200 emails that arrive at the BIPM each day are SPAM. Consequently, the IT group has reinforced the sophisticated "fire wall" protection against SPAM, and also installed a centralized system to search for and eliminate messages which contain "IT viruses".

In addition, the IT group has developed and put in place a number of intranet and internet applications, presenting new ideas and opportunities for improvement to the service offered to BIPM staff, members of Consultative Committees, to outside visitors, and those seeking to learn more about metrology and the work of the BIPM. The IT group was involved in

replacing several of the optical fiber links which serve as conduits for rapid data transfer around the site of the BIPM.

Finally, the IT group has been involved in the purchase, installation, administration and maintenance of about 170 office- or laboratory-based computers, and a dozen networked printers.

12.4 Travel (conferences and visits): Publications and Information Technology section

P.W. Martin to Bristol (United Kingdom), 17 September 2003, to the IOPP.

J.R. Miles to:

- London (United Kingdom), 28 October 2003, to the ESPERE User's Group Meeting;
- London (United Kingdom), 3-4 December 2003, to the Online conference.

J.R. Miles and J. Williams to London (United Kingdom), 12 March 2004, to the IOPP, Partners Meeting.

L. Le Mée and J.R. Miles to Puteaux (France), to the "Séminaire VERITY ULTRASEEK: Moteur de recherche Intranet/Internet", 6 April 2004.

J. Williams to CPEM 2004, London (United Kingdom), 28 June to 2 July 2004.

13 MEETINGS AND LECTURES AT THE BIPM

13.1 Meetings

The following meetings were held at the BIPM:

- The CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram met on 2 July 2003.
- The CCM Working Group on the Avogadro Constant met on 3 July 2003.
- The BIPM Summer School met from 21 July – 1 August 2003.

- The CCL met on 11-12 September 2003 preceded by its working groups on 8-10 September.
- The CCRI VERMI, Uncertainties and RMO IR CMCs Working Groups met on 23-26 September 2003.
- The 11th JCRB met on 6-7 October 2003.
- The CCEM workings groups met on 3-7 November 2003.
- The CODEX Alimentarius met on 18-19 November 2003.
- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology (JCGM) met on 24-26 November 2003 and on 15-17 March 2004, and Working Group 2 (VIM) on 17-21 November 2003, and on 8-12 March 2004, with the Uncertainty Working Group and the Key Comparison Working Group.
- The JCTLM met on 1 March 2004.
- A Joint meeting of the CIPM/ILAC/OIML Working Group met on 3-4 March 2004 at the BIPM.
- The CCTF met on 1-2 April 2004, preceded by a meeting of the CCL/CCTF Joint Working Group on 30 March and by a meeting of laboratories contributing to International Atomic Time (TAI) on 31 March.
- The CCQM met on 22-23 April 2004; it was preceded by meetings of its working groups on 15-21 April.
- The CCU met on 13-14 May 2004.
- A joint meeting of the Study Group on Comparison of Absolute Gravimeters (SGCAG) and of the CCM Working Group on Gravimetry was held on 26-27 May 2004.

13.2 Lectures

The following lectures were given at the BIPM, as part of the regular schedule of seminars:

- A. Lambrecht (ENS, Laboratoire Kastler Brossel, France): L'effet Casimir, théorie et expériences, 13 November 2003.
- P. Juncar (BNM-INM/CNAM, France): Mesure de vitesse et de déplacement par interférométrie laser hétérodyne – ou "Comment diviser la vitesse de la lumière ?", 17 December 2003.

- W. Bremser (BAM, Germany): General least squares analysis, principles, advantages, implementation, and applications, 15 January 2004.
- Jun Luo (HUST, China): Experimental tests of the photon rest mass, 28 January 2004.

13.3 Internal Seminars

- R. Köhler: The ISO/IEC 17025 Quality System and its realization at the BIPM, 3 February 2004.
- T.J. Witt: Spectrum analysis in dc electrical metrology, voltage measurements with polarity reversals, 12 February 2004.
- D. Reymann: Comparaison de systèmes Josephson à l'aide de réseaux de type SINIS, 27 April 2004.
- M. Esler: Some gas metrology underpinning the ozone project (and a brief digression on the kilogram), 11 May 2004.
- F. Arias: Mieux connaître notre planète (ou pourquoi on a eu le prix Descartes), 8 June 2004.

14 CERTIFICATES AND NOTES OF STUDY

In the period from 1 July 2003 to 30 June 2004, 72 Certificates and 8 Notes of Study were delivered.

For a list of Certificates and Notes see pages 128-134.

15 FINANCE, ADMINISTRATION AND GENERAL SERVICES (B. PERENT)

A small and efficient BIPM administration team maintains responsibility for the central finance and administrative functions. In addition to the core accounting and finance activity, the section also deals with staff matters; relations with Member States and with the French Administration; as well as various legal affairs, and a myriad issues which require a quick response such as arrangements for the smooth and safe passage of equipments for calibrations and comparisons through Customs facilities in France and elsewhere.

Together with the workshop, it also manages the site and general maintenance and, together with the Secretariat, contributes to the organization of an increased number of meetings, including the General Conference and the Summer School.

Over the period of this Report, the BIPM purchased nearly 3 million euros worth of goods, equipment and services, for which the central purchasing function is able to negotiate significant cost savings. These savings cover the costs of operation, and this year the section has introduced new software which has speeded up our on-line arrangements for purchase and approval, and reduced administrative tasks for the scientific sections.

15.1 Accounts

Details of the accounts for 2003 may be found in the "*Rapport annuel aux Gouvernements des Hautes parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures*". An abstract of Tables taken from this report may be found on pages 136-142.

The headings for the tables may be translated as follows:

Compte I : Fonds ordinaires	**Account I: Ordinary funds**
Compte II : Caisse de retraite	**Account II: Pension fund**
Compte III : Fonds spécial pour l'amélioration du matériel scientifique	**Account III: Special fund for the improvement of scientific equipment**
Compte IV : Caisse de prêts sociaux	**Account IV: Special loans fund**
Compte V : Réserve pour les bâtiments	**Account V: Building reserve**
Compte VI : *Metrologia*	**Account VI: *Metrologia***
Compte VII : Fonds de réserve pour l'assurance maladie	**Account VII: Reserve fund for medical insurance**

Two additional tables detail the payments made against budget in 2003 and the balance sheet at 31 December 2003. This is done under the headings:

Détail des dépenses budgétaires **Statement of budgetary expenditure**
Bilan au 31 décembre 2003 **Balance at 31 December 2003**

It should be noted that in all tables, since 2002, the unit of currency is the euro, according to Resolution 13 of the 21st General Conference.

15.2 Staff

15.2.1 Appointments

- Mr Sammy Courte, born 6 June 1979 in Rennes (France), French nationality, previously technician in a French private company, was appointed *technicien* in the Ionizing Radiation section from 12 November 2003.
- Dr Jeffrey H. Williams, born 13 April 1956 in Swansea (United Kingdom), British nationality, previously Communications Manager at the Leverhulme Trust in London (United Kingdom), was appointed *physicien principal*, Editor of *Metrologia*, head of the BIPM publications from 1 December 2003.
- Mrs Maria J. Fernandes, born 28 March 1951 in Bogas de Baixo (Portugal), Portuguese nationality, previously housekeeper, was appointed contractual *agent d'entretien* from 2 February 2004.
- Mrs Pauline Barat, born 13 April 1983 in Maisons-Alfort (France), French nationality, qualified from the Institut Universitaire de Technologie of Orsay (France), was engaged as *technicien* in the Mass section from 19 April 2004.
- Mrs Cecilia Kessler, born 24 March 1969 in Pergamino (Argentina), Argentinian nationality, previously Research Fellow in the Ionizing Radiation section, was engaged as *physicien* from 22 April 2004.
- Mrs Arminda Da Ponte, born 25 September 1963 in Santiago de Litem Pombal (Portugal), Portuguese nationality, previously housekeeper, was engaged as part time contractual *agent d'entretien* from 14 June 2004.
- Dr Stéphanie Maniguet, born 9 October 1972 in Saint-Julien-en Genevois (France), French nationality, previously *Research Fellow*, was engaged as *chimiste* from 17 June 2004, to work on the development and the maintenance of the BIPM key comparison database.

15.2.2 Promotions and change of grade

- Prof. Andrew J. Wallard, *directeur désigné*, took up the post of *directeur* of the BIPM from 1 January 2004 according to the decision of the CIPM during its 89th meeting in October 2000.
- Dr Leonid Vitushkin*, *physicien principal* in the Length section, was promoted *physicien chercheur principal* from 1 January 2004.
- Mr Roland Goebel*, *physicien* in the Electricity section, was promoted *physicien principal* from 1 January 2004.
- Mr Alain Picard*, *physicien* in the Mass section, was promoted *physicien principal* from 1 January 2004.
- Mrs Daniela Spelzini Etter, *secrétaire comptable* in the Finance and Administration section, was promoted *comptable principal* from 1 January 2004.
- Mr Philippe Roger, *technicien* in the Ionizing Radiation section, was promoted *technicien principal* from 1 January 2004.
- Mr Manuel Nonis, *technicien* in the Ionizing Radiation section, was promoted *technicien principal* from 1 January 2004.

15.2.3 Changes of post and transfer

Further to the decision taken by the CIPM to terminate the Photometry and Radiometry programme, Dr Michael Stock, *physicien principal*, Mr Roland Goebel, *physicien principal* and Mr Stéphane Solve, *assistant*, were transferred to the Electricity section from 1 January 2004.

- Dr Michael Stock, *physicien principal*, formerly head of the Radiometry and Photometry section, was designated head of special projects from 1 January 2004.
- Dr Rainer Köhler, formerly head of the Information Technology and Quality System section, was designated in charge of the liaison with ISO and ILAC in addition to his responsibilities as Quality Manager from 1 January 2004.
- Dr Jeffrey H. Williams, head of the BIPM publications was also designated responsible of the Information Technology group from 1 January 2004.

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* These promotions resulted from a vote of the CIPM during its 92nd meeting in October 2003.

- Mr Laurent Le Mée, previously *assistant* in the Information Technology and Quality System section, was transferred as *ingenieur informaticien* to the Publications and Information Technology section from 1 January 2004.
- Mr Gerald Petitgand, *technicien* in the Information Technology and Quality System section, was transferred to the Publications and Information Technology section from 1 January 2004.

15.2.4 Changes of titles

Titles were added to the Staff Statutes as of 1 January 2004 to take in account the present position of :

- Mr François Ausset, previously *assistant* in the Finance and Administration section, now *acheteur* from 1 January 2004.
- Mr Pascal Lemartrier, previously *maçon* in the Workshop and Building maintenance section, now *peintre* from 1 January 2004.

15.2.5 Research Fellows

- Dr Harold V. Parks, Research Fellow in the Mass section since 16 August 2001, left the BIPM on 31 December 2003 at the end of his contract to take up a post of Post-Doctoral Fellow at the Joint Institute for Laboratory Astrophysics of Colorado, Boulder (United States).

15.2.6 Departures

- Mrs Rosario Vara, contractual *femme de ménage*, retired on 31 August 2003 after 31 years of service.
- Mr Jacques Azoubib, *physicien principal* in the Time section, retired on 30 September 2003 after 30 years of service.
- Mr Jean Hostache, *technicien métrologiste* in the Mass section, retired on 30 September 2003 after nearly 38 years of service.
- Mr Christian Veyradier, *technicien principal* in the Ionizing Radiation section, retired on 30 September 2003 after 40 years of service.
- Mrs Michèle Thomas, *technicien principal* in the Time section, retired on 30 September 2003 after nearly 37 years of service.

- Mr Christian Colas, *technicien métrologiste* in the Ionizing Radiation section, retired on 31 December 2003 after 41 years of service.
- Mr Daniel Avrons, *technicien principal* in the Electricity section, retired on 31 December 2003 after 32 years of service.
- Prof. Peter W. Martin, *physicien principal*, Editor of *Metrologia* and head of the BIPM publications since 1 June 1998, retired on 31 January 2004 after nearly 6 years of service.

On their retirement, the Director thanked each of these members of staff for the effective and devoted service during their years at the BIPM.

- Mr Sokhona Youssouf, contractual *agent d'entretien* since 1 June 2003 left the BIPM on 15 December 2003.
- Dr Terence J. Quinn, *directeur* of the BIPM since 1 August 1988, retired on 31 December 2003 after 26 years of service marked by outstanding developments in the activity of the BIPM.

At the 92nd meeting of the CIPM the members of the Committee expressed their gratitude to him for his achievements during his tenure as Director of the BIPM.

15.3 Buildings

The BIPM site at Sèvres contains several historic buildings as well as extensive grounds. Some buildings are used as accommodation and offices and some as laboratories. The cost of maintaining these historical buildings, in addition to the cost for maintenance of the more modern buildings is increasing and the site services team is involved in a programme of planed maintenance and refurbishment as resources permit. The last General Conference recognized that the proportion of the budget allocated to maintenance and to adequate laboratory facilities had fallen in recent years and supported the proposal to return it to previous levels. Contracted out services are used wherever possible; for example, for cleaning and servicing of air conditioning, but local support is essential and provides on-the-spot help for urgent work as well as a dedicated team of individuals who put a high priority on the care of the BIPM environment and its staff.

15.3.1 Grand Pavillon

- Renovation of the Director's apartment.
- Redecoration of the corridor.

15.3.2 Petit Pavillon

- Painting of the first floor of the caretaker's apartment.

15.3.3 Observatoire

- Refurbishment of room 12.
- Redecoration of an office in the first floor.

15.3.4 Ionizing Radiation building

- Refurbishment of rooms R21 and R22.
- Redecoration of rooms R13, R19 and R20.

15.3.5 Nouveau Pavillon

- Redecoration of the Director's office.

15.3.6 All buildings

- Replacement of the circuit breakers in the transformer room for global protection of the buildings.

15.4 Travel (lectures and visits): Finance, administration and general services section

B. Perent to:

- Brussels (Belgium), 27-28 April 2004, to attend the Third Workshop on Pensions in International Organizations organized by the Joint Pensions Administrative Section of the Coordinated Organizations and the United Nations Joint Staff Pension Fund hosted by Eurocontrol: lecture on the historical background and present operation of the BIPM Pension fund;
- Washington DC (United States), 27-28 May 2004, to attend a meeting on privileges and immunities in international organisations organized by

the International Institute of Administrative Sciences and hosted by the World Bank.

16 SECRETARIAT (F. JOLY)

The Secretariat of the BIPM is a small group consisting of four individuals, including the Head of the section who is also the Personal Assistant to the Director of the BIPM. In addition, the librarian of the BIPM, who is involved in production of the BIPM's publications and their translation into French, is also a member of the Secretariat.

The workload on the Secretariat continues to increase with the rise in the number of meetings held at the BIPM (about 30 % more than last year) which, this year, included the BIPM Metrology Summer School, a number of Consultative Committees and Working Groups, and the General Conference on Weights and Measures. In order to cope with the organization of these meetings, and the evolution of administrative work, the Secretariat is continuing to develop its knowledge of IT tools, so that our most important documents for Consultative Committees or for communications with Member States and NMI Directors can be accessed from the BIPM's website.

17 WORKSHOP AND SITE MAINTENANCE (J. SANJAIME)

The BIPM workshop provides an essential and much-valued contribution to our work programme. Many of its activities are mentioned in the reports of individual sections but its core mission is to support the technical programme in the construction of specialized apparatus and, where necessary, to assist when NMIs and others bring items for calibration. In the latter case, ancillary equipment is often needed at short notice to deal with any problems or to

make repairs if equipment is damaged in transit so that the calibration can proceed smoothly. This fast response work is critical to the efficiency of our service to NMI staff who may only be at the BIPM for fixed, short periods of time.

The workshop carries out high-precision mechanical work for the scientific sections of the BIPM. Among recent projects we mention in particular:

- SRP optical bench for the Chemistry section, July 2003;
- calculable capacitor, in collaboration with the NML-CSIRO (Australia), April 2004: study, design, and fabrication of a control device for the high-precision bars.

In addition, the workshop is the only world source of platinum iridium prototype kilograms, which are made exclusively for the Metre Convention and which makes use of the specialized equipment and unique expertise of the workshop staff.

During the period covered by this report, the workshop manufactured the following mass prototypes:

- six kilogram prototypes (Nos. 86, 87, 88, 89, 90 and 91) (prototypes Nos. 86 and 87 were delivered in July 2003; Nos. 88 and 89 in August 2003; Nos. 90 and 91 in December 2003);
- one kilogram prototype for the BIPM (delivered in July 2004);
- two 500 g prototypes (delivered in April 2004).

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences*

AGAL**	Australian Government Analytical Laboratories
AIST*	National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST
AMCTM	Advanced Mathematical and Computational Tools in Metrology Conference
ANSTO	Australian Nuclear Science and Technology Organization, Menai (Australia)
AOS	Astrogeodynamical Observatory, Borowiec (Poland)
APL	Applied Physics Laboratory, John Hopkins University, Laurel (United States)
APMP	Asia/Pacific Metrology Programme
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
BAM	Bundesanstalt für Materialforschung und -prüfung, Berlin (Germany)
BEV	Bundesamt für Eich- und Vermessungswesen, Vienna (Austria)
BIPM	International Bureau of Weights and Measures/ Bureau International des Poids et Mesures
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung, Bonn and Berlin (Germany)
BNM	Bureau National de Métrologie, Paris (France)
BNM-INM	Bureau National de Métrologie, Institut National de Métrologie, Paris (France)
BNM-LNE	Bureau National de Métrologie, Laboratoire National d'Essais, Paris (France)
BNM-LNHB	Bureau National de Métrologie, Laboratoire National Henri Becquerel, Gif-sur-Yvette (France)

* Organizations marked with an asterisk either no longer exist or operate under a different acronym.

** Since 1 July 2004, this laboratory is incorporated in the National Measurement Institute, Australia, NMIA.

BNM-SYRTE	Bureau National de Métrologie, Systèmes de Référence Temps Espace, Observatoire de Paris (France)
CC	Consultative Committee of the CIPM
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration/Comité Consultatif de l'Acoustique, des Ultrasons et des Vibrations
CCEM	Consultative Committee for Electricity and Magnetism/ Comité Consultatif d'Électricité et Magnétisme
CCL	Consultative Committee for Length/ Comité Consultatif des Longueurs
CCM	Consultative Committee for Mass and Related Quantities/ Comité Consultatif pour la Masse et les Grandeurs Apparentées
CCPR	Consultative Committee for Photometry and Radiometry/ Comité Consultatif de Photométrie et Radiométrie
CCQM	Consultative Committee for Amount of Substance: Metrology in Chemistry/Comité Consultatif pour la Quantité de Matière : Métrologie en Chimie
CCRI	Consultative Committee for Ionizing Radiation/ Comité Consultatif des Rayonnements Ionisants
CCT	Consultative Committee for Thermometry/ Comité Consultatif de Thermométrie
CCTF	Consultative Committee for Time and Frequency/ Comité Consultatif du Temps et des Fréquences
CCU	Consultative Committee for Units/Comité Consultatif des Unités
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
CENAMET	Centro Nacional de Metrología de Panamá (Panamá)
CGGTTS	CCTF Group on GPS Time-Transfer Standards
CGPM	General Conference on Weights and Measures/ Conférence Générale des Poids et Mesures
CIATEC	Centro de Investigación y Asesoría Tecnológica A.C., Guanarato (Mexico)
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid (Spain)
CIPM	International Committee for Weights and Measures/ Comité International des Poids et Mesures
CLEO	Conference on Lasers and Electro Optics

CMI	Český Metrologický Institut/Czech Metrological Institute, Prague and Brno (Czech Rep.)
CMS-ITRI	Centre for Measurement Standards of the Industrial Technology Research Institute (Chinese Taipei)
CNAM	Conservatoire National des Arts et Métiers, Paris (France)
CNEA	Comisión Nacional de Energía Atómica, Buenos Aires (Argentina)
CNES	Centre National d'Études Spatiales, Toulouse (France)
CNRS	Centre National de la Recherche Scientifique, Paris (France)
CONICET	Argentine Council of Research
COPUOS	Committee on the Peaceful Uses of Outer Space of the United Nations
CPC	Conventions Product Centre of the IERS, see IERS
CPEM	Conference on Precision Electromagnetic Measurements
CRL*	Communications Research Laboratory, see NICT
CSIR-NML	Council for Scientific and Industrial Research, National Measurement Laboratory, Pretoria (South Africa)
CSIRO**	Commonwealth Scientific and Industrial Research Organization, see NML-CSIRO
EC-JRC	European Community, Joint Research Centre, Brussels (Belgium)
ECNU	East China Normal University, Shanghai (China)
EFTF	European Frequency and Time Forum
EIM	Hellenic Institute of Metrology, Athens (Greece)
EMPA	Swiss Federal Laboratories for Materials Testing and Research, St Gall (Switzerland)
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENEA-INMRI	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (ENEA-INMRI), Casaccia (Italy)
ENS	École Normale Supérieure, Paris (France)
ERLAP	European Reference Laboratory for Air Pollution, Ispra (Italy)
EUROMET	European Collaboration in Measurement Standards
FCS	Frequency Control Symposium
FMI	Finnish Meteorological Institute, Helsinki (Finland)

GREX	Groupe de Recherche du CNRS: Gravitation et Expériences (France)
GT-RF	CCEM Working Group on Radiofrequency Quantities
HIRCL	Hellenic Ionizing Radiation Calibration Laboratory, Athens (Greece)
HUST	Huazhong University of Science and Technology (China)
IAC	International Avogadro Coordination Committee
IAEA	International Atomic Energy Agency
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICAG	International Conference of Absolute Gravimeters
ICC	International Chamber of Commerce, Geneva (Switzerland)
ICRM	International Committee for Radionuclide Metrology
ICRS	International Celestial Reference System
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers, Piscataway, NJ (United States)
IEM DEP	Instituto de Engenharia Mecânica da EFEI, Itajubá-MG (Brazil)
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italy)
IERS	International Earth Rotation Service
IFCC	International Federation of Clinical Chemistry and Laboratory Medicine
IFIN	Institutul de Fizica si Inginerie Nucleara, Bucarest (Romania)
IGLOS-PP	International GLONASS Service Pilot Project
IGN	Institut Géographique National, Saint-Mandé (France)
IGS	International GPS Service for Geodynamics
ILAC	International Laboratory Accreditation Cooperation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
IMGC-CNR	Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche, Turin (Italy)
INM*	Institut National de Métrologie, see BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial, Rio de Janeiro (Brazil)
INPL	National Physical Laboratory of Israel, Jerusalem (Israel)

INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentina)
INTMET	EUROMET Interdisplinary Metrology Group
ION	Institute of Navigation, Alexandria, VA (United States)
IOP	Institute of Physics, London (United Kingdom)
IOPP	Institute of Physics Publishing, London (United Kingdom)
IPE RAS	Center of Geophysical Data Studies and Telematics Applications, Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, Moscow (Russian Fed.)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRMM	Institute for Reference Materials and Measurements, European Commission
ISCIII	Instituto de Salud Carlos III, Madrid (Spain)
ISO	International Organization for Standardization
ISO CASCO	International Organization for Standardization, Conformity Assessment Committee
ISO REMCO	International Organization for Standardization, Committee on Reference Materials
ITU	International Telecommunication Union
IUPAC	International Union of Pure and Applied Chemistry
IVS	International VLBI Service
JCDCMAS	Joint Committee on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization
JCGM	Joint Committee for Guides in Metrology
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
JCTLM	Joint Committee on Traceability in Laboratory Medicine
JILA	Joint Institute for Laboratory Astrophysics, Boulder, CO (United States)
KFDA	Korea Food and Drug Administration, Seoul (Rep. of Korea)
KRISS	Korea Research Institute of Standards and Science, Daejeon (Rep. of Korea)
LGC	Laboratory of the Government Chemist, Teddington (United Kingdom)
LNE*	Laboratoire National d'Essais, see BNM-LNE

LNHB*	Laboratoire National Henri Becquerel, see BNM-LNHB
LNMRI	Laboratório Nacional de Metrologia das Radiaçoes Ionizantes, Rio de Janeiro (Brazil)
MAC	UK Department of Trade and Industry Measurement Advisory Committee
METAS	Swiss Federal Office of Metrology and Accreditation, Bern and Wabern (Switzerland)
MIKES	Mittatekniikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finland)
MRA	Mutual Recognition Arrangement
NAB	National Accreditation Body
NARL	National Analytical Reference Laboratory, Canberra and Pymble (Australia)
NCSLI	National Conference of Standards Laboratories, Boulder, CO (United States)
NEL	National Engineering Laboratory, Glasgow (United Kingdom)
NICT	National Institute of Information and Communications Technology, Tokyo (Japan)
NIM	National Institute of Metrology, Beijing (China)
NIMT	National Institute of Metrology, Bangkok (Thailand)
NIS	National Institute of Standards, Cairo (Egypt)
NIST	National Institute of Standards and Technology, Gaithersburg, MD (United States)
NMi VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NMI	National Metrology Institute
NMIA	National Measurement Institute, Australia, Lindfield (Australia)
NMIJ/AIST	National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba (Japan)
NML	National Metrology Laboratory, Dublin (Ireland)
NML-CSIRO**	National Measurement Laboratory, CSIRO, Lindfield (Australia), see NMIA
NPL	National Physical Laboratory, Teddington (United Kingdom)
NPLI	National Physical Laboratory of India, New Delhi (India)
NRC	National Research Council of Canada, Ottawa (Canada)

NRPA	Norwegian Radiation Protection Authority, Østerås (Norway)
NTSC	National Time Service Centre, Lintong (China)
OCA	Observatoire de la Côte d'Azur, Grasse (France)
OIML	International Organization of Legal Metrology/ Organisation Internationale de Métrologie Légale
OMH	Országos Mérésügyi Hivatal/National Office of Measures, Budapest (Hungary)
OMP	Observatoire Midi-Pyrénées, Toulouse (France)
OP	Observatoire de Paris (France)
ORB	Observatoire Royal de Belgique, Brussels (Belgium)
PITTCON	Pittsburgh Conference
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
PTTI	Precise Time and Time Interval Applications and Planning Meeting
RC	Radioisotope Centre, Otwock (Poland)
RCMAM	IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology
RMO	Regional Metrology Organization
SCAG	Study Group on Comparisons of Absolute Gravimeters
SCSLI	National Conference of Standards Laboratories International
SIC	Superintendencia de Industria y Comercio, Bogotá (Colombia)
SIM	Sistema Interamericano de Metrología
SIRIM	National Metrology Laboratory (NML-SIRIM), Shah Alam (Malaysia)
SP	SP Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
SRC	Space Research Centre of the Polish Academy of Sciences, Warsaw (Poland)
SSDL	Secondary Standards Dosimetry Laboratories, see IAEA
STUK	Säteilyturvakeskus, Helsinki (Finland)
SURAMET	South American Metrology Cooperation (Argentina, Brazil, Chile, Paraguay and Uruguay)
SYRTE*	Bureau National de Métrologie, Systèmes de Référence Temps Espace, see BNM-SYRTE

TempMeko	International Symposium on Temperature and Thermal Measurements in Industry and Science
TL	Telecommunication Laboratories, Chung-Li (Chinese Taipei)
UBA	Umweltbundesamt, Berlin (Germany)
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
UN	United Nations
UNIDO	United Nations Industrial Development Organization
USNO	U.S. Naval Observatory, Washington DC (United States)
USNRL	U.S. Naval Research Observatory, Washington DC (United States)
UWA	University of Western Australia, Crawley WA (Australia)
VERMI	Virtual European Radionuclide Metrology Institute
VNIIFTRI	All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Gosstandart of Russia, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleyev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, see NMi VSL
WG	Working Group
WGAC	CCM Working Group on the Avogadro Constant
WGLF	CCEM Working Group on Low-frequency Quantities
WHO	World Health Organization
WMO	World Meteorological Organization
WTO	World Trade Organization

2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
CCD	Charge-coupled Device
CMC	Calibration and Measurement Capabilities
COSSH	Control of Substances Hazardous to Health
CRM	Certified Reference Material
DEA	Diplôme d'Études Approfondies
EAL	Free Atomic Time Scale/Échelle Atomique Libre
EMF	Electro-motive Force
FTIR	Fourier Transform Infrared Technique
GLONASS	Global Navigation Satellite System
GLS	Generalized Least Square

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPT	Gas-phase Titration
GUM	Guide to the Expression of Uncertainty in Measurement
HTML	Hypertext Mark-up Language
ICRF	International Celestial Reference Frame
IT	Information Technology
IUT	Institut Universitaire de Technologie
IVS	International VLBI Service
KCDB	BIPM Key Comparison Database
KCRV	Key Comparison Reference Value
KTP	Potassium Titanyle Phosphate
MFC	Mass Flow Controller
MWL	Microwave Link
PFS	Primary Frequency Standard
QHE	Quantum Hall Effect
SI	International System of Units/Système International d'Unités
SINIS	Superconductor-insulator metal-normal-insulator-super-conductor
SIR	International Reference System for gamma-ray emitting radionuclides/Système International de Référence pour les mesures d'activité d'émetteurs de rayonnement gamma
SIS	Superconductor-insulator-superconductor
SME	Standard Model Extension
SRP	Standard Reference Photometer
TA	Atomic Time
TAI	International Atomic Time/Temps Atomique International
TCU	Temperature Control Unit
TT	Terrestrial Time
TWSTFT	Two-way Satellite Time and Frequency Transfer
UTC	Coordinated Universal Time
VIM	International Vocabulary of Basic and General Terms in Metrology
VLBI	Very Long Baseline Interferometry
YAG	Yttrium Aluminium Garnet

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